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INFORMATION CIRCULAR

ANNUAL REPORT OF RESEARCH AND TECHNOLOGIC WORK ON COAL, FISCAL YEAR 1941

BY

A. C. FIELDNER AND L. D. SCHMIDT

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UNITED STATES DEPARTMENT OF THE INTERIOR - BUREAU OF MINES

ANNUAL REPORT OF RESEARCH AND TECHNOLOGIC WORK ON COAL FISCAL YEAR 1941[1]

By Arno C. Fieldner[2] and L. D. Schmidt[3]

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FOREWORD

Much activity is called for in the present period of heightened national effort, and wise direction of such a program must always be conditioned by positive knowledge gained in years of slow and painstaking study and development. Research and technologic investigations on coal by the Bureau of Mines have been described in a series of annual

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reports[4] of which this is the sixth. These investigations increase our fund of exact knowledge on the properties and composition of American coals and lead to better methods in mining, preparing, storing, and utilizing coal.

ACKNOWLEDGMENTS

This circular has been prepared from reports by the supervising heads of all sections in the Coal Division and of certain sections in the Mining, Nonmetals, and Explosives Divisions, as well as from recent publications by members of these divisions. Special acknowledgments are due to the following members of the Technologic Branch staff:

Coal Division

J. F. Barkley, supervising engineer, fuel economy service section.
H. M. Cooper, supervising chemist, coal analysis section.
J. D. Davis, supervising chemist, coal carbonization section.
H. P. Greenwald, superintendent, Central Experiment Station, and supervising engineer, experimental coal-mine section.
P. Nicholls, supervising engineer, fuels section.
V. F. Parry, supervising engineer, subbituminous coal and lignite section.
W. A. Selvig, supervising chemist, coal constitution and miscellaneous analysis section.
N. H. Snyder, supervising engineer, fuel-inspection section.
H. H. Storch, supervising chemist, coal-hydrogenation and physical-chemistry section.

Explosives Division

W. J. Huff, consulting explosives chemist.
M. A. Elliott, gas engineer.
G. W. Jones, chemist.
J. E. Tiffany, explosives testing engineer.

[4] Fieldner, A. C., Resume of Research and Technologic Work Relating to Coal Conducted by the Technologic Branch During 1936: Bureau of Mines Inf. Circ. 6935, 1937, 14 pp. Annual Report of Research and Technologic Work on Coal, Fiscal Year 1937: Bureau of Mines Inf. Circ. 6992, 1938, 44 pp. Annual Report of Research and Technologic Work on Coal, Fiscal Year 1938: Bureau of Mines Inf. Circ. 7052, 1939, 44 pp.
Fieldner, A. C., and Brewer, R. E., Annual Report of Research and Technologic Work on Coal, Fiscal Year 1939: Bureau of Mines Inf. Circ. 7105, 1940, 59 pp.
Fieldner, A. C., and Rice, W. E., Annual Report of Research and Technologic Work on Coal, Fiscal Year 1940: Bureau of Mines Inf. Circ. 7143, 1940, 50 pp.

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A. L. Toenges, supervising engineer, coal-mining section.

Nonmetals Division

O. C. Ralston, chief engineer.
W. H. Coghill, supervising engineer, Southern Experiment Station.
H. F. Yancey, supervising engineer, Northwest Experiment Station.

Acknowledgment is made also of the cooperation of the following institutions and organizations:

American Society for Testing Materials.
Bituminous Coal Research, Inc.
Canadian Bureau of Mines.
Colorado School of Mines.
Crucible Fuel Co.
Koppers Co.
Northern Colorado Coals, Inc.
Oregon Department of Geology and Mineral Industries.
Research Council of Alberta.
University of Alabama.
University of North Dakota.
University of Washington.

PROPERTIES AND COMPOSITION OF AMERICAN COALS

Inspection, Sampling, and Analysis

The Bureau of Mines operates a coal-analysis laboratory as a service facility for all Government agencies. The national defense program prompted a heavy demand, especially from the War Department, for coal analyses to be used in connection with coal bids. Three coal-sampling trucks operated throughout the year. Samples were taken at all coal-producing mines in Michigan, and many samples were collected from other localities in connection with Government coal contracts and upon requests from prospective bidders on contracts as well as for classification purposes in cooperation with the Bituminous Coal Producers Board. For the first time it was possible to extend coal-sampling work to the Western States.

For the general use of the Government in making purchases and for information for public use, coal was inspected and 82 tipple samples and a face sample were collected at 32 mines in Colorado, and 124 tipple samples at 43 mines and 43 face samples at 12 mines in New Mexico. Coal was inspected and samples were collected at 50 mines in Arkansas, 39 mines in Oklahoma, 8 mines in Washington, 2 mines in Texas, 8 mines in Iowa, 3 mines

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in Kansas, 6 mines in Missouri, 17 mines in Illinois, 7 mines in Kentucky, 23 mines in Maryland, 9 mines in Michigan, 41 mines in Pennsylvania, 13 mines in West Virginia, and 1 mine in Alabama.

For the use of the Government departments in determining awards of contracts for anthracite, coal was inspected and 75 samples were collected at 14 breakers in the Pennsylvania anthracite field. In cooperation with the Bituminous Coal Producers Board for District 2, a total of 176 tipple samples was collected at 56 mines in western Pennsylvania.

In all, 1,145 tipple samples were taken at 378 mines, 87 face samples at 25 mines, 6 samples for carbonization, and 8 column samples for microscopic examination.

The coal-analysis laboratory received and analyzed 10,003 samples during the year, making 116,967 determinations. This is approximately 10 percent above the average for the 10 preceding years.

About one-half of the total number of samples were analyzed for the War and Navy Departments, about one-fourth for other Government agencies, and the remainder in connection with safety and research work of the Bureau of Mines. Forts and Training centers submitted an unusually large number of samples for analysis.

Properties of Washington Coals

From time to time, the Bureau has published coal analyses by separate States to show the character and quality of the coals currently mined and marketed. A recent publication covers the analyses, production, distribution, and use of Washington coals.5/ These coals show a wide range in analysis. Although deposits of coals ranging in rank from lignite to anthracite occur in the State, current production is limited to coals of bituminous and subbituminous rank. Bituminous coal constitutes about three-fourths of the total production in the State. A striking feature of the Washington coal industry during the past decade has been the increased number of producing mines, despite a decline (to 1940) in both total output and number of men employed. Because many of the coal beds of Washington contain a considerable amount of impurities, such as shale, the greater part of the coal is cleaned mechanically before marketing.

Mathematical Theory of Coal Sampling

An extensive study was made of the principles underlying the prediction of accuracy in coal sampling with respect to the weight and number of increments of the gross sample. The method of analysis developed introduces the idea that each lot of coal to be sampled has definite physical properties,

5/ Yancey, H. F., Geer, M. R., Daniels, J., Snyder, N. H., Swingle, R. J., Cooper, H. M., and Abernethy, R. F., Analyses of Washington Coals, Supplement to Technical Paper 491; Bureau of Mines Tech. Paper 618, 1941, 81 pp.

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which are defined as the "sampling characteristics." These characteristics are the properties of the individual pieces of coal for weights and ash percentages (if that is the quality sought) and the arrangements of the pieces in the lot of coal with respect to their weights and to their ash percentages.

The analysis has developed the relationship between the sampling requirements and the sampling characteristics. If the sampling characteristics are known, the number of increments of a given weight to insure a specified type and degree of accuracy can be predicted exactly.

A summary of this development has been submitted to the Committee on Coal Sampling of the American Society for Testing Materials for its consideration in the preparation of a coal-sampling specification. A short paper outlining the principles was presented at the Fuels Meeting of the American Society of Mechanical Engineers and the American Institute of Mining and Metallurgical Engineers at Birmingham, Ala., in November 1940.

Classification of American Coals.

Moisture Characteristics

In the specifications for the classification of coal by rank the lower-rank coals are classified according to heating value per pound upon the moist basis, that is, containing the natural bed moisture. To bring to this basis coals that show visible surface moisture or that have partly dried in the mine, an equilibration method devised by Stansfield and Gilbart[6] is used, by which the moisture-holding capactiy of coal at 100 percent humidity is determined. The moisture content of a sample treated in this manner is assumed to equal the true bed moisture. During the year, the Bureau of Mines, in cooperation with the Canadian Bureau of Mines and the Research Council of Alberta, tested coal samples from mines of the western United States and Canada to determine how well the various laboratories could check moisture values using the equilibration method. Inspection of table 1 shows that, in general, the moisture values obtained by the Bureau of Mines are slightly lower than those of the two other laboratories. Those differences are due in part to the fact that the moisture determinations of the Bureau of Mines were made in an oven through which dry air was circulated instead of an inert gas that was used by the other laboratories. Tests of several coals have shown that the moisture values may be as much as 0.4 percent lower when air rather than carbon dioxide is used as the drying atmosphere.

6/ Stansfield, Edgar, and Gilbert, K. C., Moisture Determination for Coal Classification: Trans. Am. Inst. Min. and Met. Eng., vol. 101, Coal Division, 1932, pp. 125-143.

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TABLE 1. - Check results of moisture determination by equilibration method

State or Province	County or area	Mine	Bureau of Mines	Canadian Bureau of Mines	Research Council of Alberta
Alberta	Camrose	Rod Flame	28.0	1/	28.7
Do.	Do.	Stoney Creek	26.3	1/	26.1
Do.	Castor	Armstrong	29.8	1/	30.3
Do.	Do.	Stradier	25.7	1/	27.0
Do.	Pakowki	Perini	22.9	1/	24.3
Do.	Sheerness	Blackburn	23.5	1/	24.3
Do.	Do.	Blossom	24.1	1/	24.0
Colorado	Boulder	Lewis No. 2	17.6	18.3	18.4
Do.	Do.	Do.	18.4	19.1	1/
Do.	Jackson	Sudduth	17.3	18.0	1/
Do.	Jefferson	Caprock	23.4	24.1	24.0
Do.	Do.	Do.	23.8	24.8	1/
Do.	Weld	Eagle	21.9	23.2	1/
Do.	Do.	Do.	22.7	24.0	23.5
Montana	Rosebud	Colstrip	25.6	25.0	1/
North Dakota	Burleigh	Burleigh	39.1	39.0	1/
Do.	Mercer	Knife River	34.1	33.8	1/
Wyoming	Campbell	Wyodak	31.8	30.4	1/
Do.	Sheridan	Monarch No. 45	23.8	24.6	1/
Do.	Sweetwater	Clark	11.1	11.8	12.1

1/ Not reported.

Constancy of Value of "Pure" Coal in British Thermal Units

There is a general concept in the coal trade that the heating value of moisture- and ash-free coal from the same seam or surely from the same mine is substantially a constant; that calculation of this value from the proximate analysis and British thermal units determined in the laboratory will reveal whether or not a coal came from a given area or seam; and that, having this constant, the value of a coal sample in British thermal units can be calculated fairly closely upon a dry or as-received basis from the moisture and ash values of its proximate analysis.

To determine possible limitations or accuracies in the practical use of this general hypothesis, a number of coal analyses from the laboratories of the Bureau of Mines were studied.1/

The average heating value (moisture- and ash-free basis) of the coal from each mine was calculated, as well as the average amount of deviation from this value for the various analyses reported for the mine.

1/ Barkley, J. F., and Burdick, L. R., Constancy of B.t.u. Value of "Pure" Coal: Bureau of Mines Rept. of Investigations 3572, 1941, 10 pp.

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It is interesting to note that this average deviation increased regularly from 30 B.t.u. per pound for medium-volatile coals to 155 B.t.u. for lignites. No satisfactory explanation of this fact has been advanced.

Friability and Grindability of Coals

Friability and grindability tests have been made on samples of coal from 47 mines in 17 different beds in Alabama coal fields,3/ concluding a comprehensive survey made in cooperation with the University of Alabama.

The friability of coal or its tendency to break into smaller sizes in the course of handling is measured by tumbling a sample of 1-1/4-inch coal in a special ball mill and determining by screen analyses the amount of reduction in size. Although the correlation between friability and volatile matter is not good, there is a general increase in friability with decreasing volatile matter. In other words, in general the lower-volatile bituminous coals break more easily on handling.

The standard grindability test was designed to give users of pulverized coal further information concerning the relative ease of grinding different coals. There is fairly good correlation between the grindability and the volatile-matter content of the coals tested - the grindability increasing from about 30 to 60 when the volatile-matter content decreases from 40 to 30 percent (moisture- and ash-free basis).

Physical and Chemical Properties of Subbituminous Coal and Lignite

Subbituminous coal, lignite, and other noncaking western coals have properties that differ widely from those of coking coals. A systematic study of the high-oxygen coals has been made during the last 3 years, and some investigations were completed during the current year. A survey of 18 mines that produce 75 percent of the coal in the Northern Colorado field was made to determine the physical and chemical properties of normal 2-1/2-inch slack. This study included: Size composition, friability, slacking, chemical analysis and heating value of different sizes, bulk density, and specific gravity. Similar studies were made of samples obtained from mines in other parts of the subbituminous and lignite fields. The average physical and chemical properties of 2-1/2-inch slack are shown in table 2.

Relation of Petrographic Composition to Chemical and Physical Properties of Coal

Petrographic analyses of many coal beds have been made by examining, under the microscope, samples that were taken at regular intervals from the floor to the top of the bed. The coal bands in the bed are classified as bright, splint, or semisplint in type, and the relative amounts of each of these three types are reported for each coal bed.

3/ Hertzog, E. S., Cudworth, J. R., Selvig, W. A., and Ode, W. H., Friability, Grindability, Chemical Analyses, and High-and-Low Temperature Carbonization of Alabama Coals: Bureau of Mines Tech. Paper 611, 1940, 59 pp.

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TABLE 2. - Physical and chemical properties of average 2-1/2-inch subbituminous slack, Northern Colorado field, District 16

Proximate analysis:[1]	
As-received basis	
Moisture	22.0
Volatile matter	29.7
Fixed carbon	42.6
Ash	5.7
Sulfur	.5
B.t.u.	9,550
Ash- and moisture-free basis	
Volatile matter	41.1
Fixed carbon	58.9
Sulfur	.7
B.t.u.	13,210
Ash-softening temp. - °F.	2,110
Specific gravity [2]	1.29
Weight per cubic foot - lb.[3]	48.9
Slacking index[4]	49.6
Friability	
D441-37T[5]	23.6
T.P. 512[6]	29.7

Size composition:[7]	
Screen size: Round hole, inches	Cumulative percent retained
2-1/2	2.2
2	10.4
1-1/2	23.4
1-1/4	31.1
1	40.9
3/4	52.1
1/2	63.9
3/8	72.0
0	100.0
Square hole, inches	
2	2.2
1-1/2	12.8
1	31.8
3/4	43.8
1/2	58.6
1/4	73.3
1/8	83.2
0	100.0

1/ H. M. Cooper, Central Experiment Station, Bureau of Mines, Pittsburgh, Pa. Average of 18 mines that supply 75 percent of coal produced in Northern Colorado field.
2/ Golden, Colo., Field Station. Average of 37 samples. Determinations made by water-displacement method on fresh 1- by 1-1/2-inch lumps.
3/ Golden, Colo., Field Station. Average of 11 samples.
4/ W. A. Selvig, Central Experiment Station. Average of first cycle slacking index of 14 samples.
5/ H. F. Yancey, Northwest Experiment Station, Seattle, Wash. Average of 19 samples of fresh 1- by 1-1/2-inch lumps.
6/ H. F. Yancey, Northwest Experiment Station. Average of 13 samples of fresh 1- by 1-1/2-inch lumps.
7/ Golden, Colo., Field Station. Average of 18 mines as noted in 1/.

The bands of splint coal are distinguishable from the bands of ordinary bright coal by their dull, grayish-black color. Splint is hard, solid, and tough and breaks with an irregular, rough, splintery fracture. In mining,

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it breaks into large lumps and slabs with almost no slacks or fines. American splint coals are of the same type as the durains of England and the mattkohle of Germany.

A recent study of the splint coals of the Appalachian region[9] brought out some interesting facts about this important type of coal. Splint coals are easily identified by examining, under the microscope, thin sections illuminated by transmitted light. They are characterized by a semiopaque to opaque ground mass or attritus, whereas the bright-coal sections have a ground mass or attritus predominantly translucent.

The petrographic study of 55 coal columns selected from representative coals in the Appalachian region showed the presence of relatively large percentages of splint coal in beds of the Upper Pottsville (Kanawha formation). The prevalence of sprint-type coal does not end at the close of the Pottsville but extends into the Brookville coal, the basal member of the Allegheny formation in Pennsylvania. The coals above the Brookville average about 2 percent splint coal. The coals from the New River and Pocahontas formations that were examined contained only thin bands of splint and semisplint. The New River coal averaged 11 percent splint coal; the Pocahontas, 5 percent.

New evidence has been brought to bear upon one of the most difficult problems of the coal paleobotanist, that is, a logical explanation of the origin and formation of splint coal. This evidence confirms the belief that the splint coals were laid down under conditions especially favorable to the action of biological agencies, thus bringing about a high degree of decomposition and maceration of the plant material. The opaque matter results from such an advanced stage of decomposition; and the further the decay progressed, the more opaque matter was formed and the greater its degree of opacity.

The splint-coal layers selected from 17 different coal beds were found to have an appreciably higher carbon content (moisture- and mineral-matter-free basis) than the bright coals of the same beds. Generally they had a higher ash content and a higher ash-fusion temperature. The bright coals generally had the highest content of moisture, hydrogen, nitrogen, and oxygen and the lowest calorific value.

Both bright and splint coal showed the same content of volatile matter when they had equal contents of spores and resins.

Origin of Coal

A technical paper on coal paleobotany[10] was prepared from material on which Dr. Thiessen was working at the time of his death in 1938. This paper

9/ Sprunk, G. C., Ode, W. H., Selvig, W. A., and O'Donnell, H. J., Splint Coals of the Appalachian Region; Their Occurrence, Petrography, and Comparison of Chemical and Physical Properties with Associated Bright Coals: Bureau of Mines Tech. Paper 615, 1940, 59 pp.

10/ Thiessen, R., and Sprunk, G. C., Coal Paleobotany: Bureau of Mines Tech. Paper 631, 1941, 56 pp.

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brings to the attention of paleobotanists the fact that in coal an enormous amount of material in a remarkably good state of preservation is at their disposal. A large proportion of coals and particularly the bright bands thereof (anthraxylon or vitrain) are composed of constituents that invariably have retained some of the original plant structures. This paper discusses the identity of these plants and of the remains.

In the Paleozoic coals, plants of three types are easily recognized: Coniferouslike, cycadophyte, and lycopod. No other types have been identified with certainty. The coniferouslike plants of the Paleozoic era, the cordaitales, are represented in coal by the xylem, bark, and leaves and by resinous inclusives thereof. Xylem (fig. 1) occurs most often in the thicker bands. The most easily recognized lycopod tissues are from the periderm or outer bark (fig. 2). The periderm of the lycopods was a very thick walled, highly lignified tissue that has resisted the peat- and coal-forming processes more than other tissues, hence has remained in larger proportions. Leaves, leaf bases, sporangia, and spores from lycopods also are illustrated. Cycadophytes were abundant contributors to the Paleozoic coals. The cycadophytes are represented in coal by the xylem, periderm, leaves, and resinous cell contents and particularly by the mucilaginous contents of the so-called gum ducts, as in figure 3.

The lycopod, cycadophyte, and coniferouslike remains observed in thin sections of coal can be compared with similar remains in thin sections of coal can be compared with similar remains in thin sections of coal balls; a number of illustrations of the latter are included in the report.

Petrography of Coal as a Measure of Amenability to Hydrogenation

Microscopic examination of coal aids in predicting the yields of oil obtainable on hydrogenation.[11]

A petrographic survey is being made of lignites and subbituminous and bituminous coals of the Western States to help in the selection of suitable coals for large-scale hydrogenation tests. This survey has included two exceptionally thick beds of coal. One was the 26.8-foot bed of the Colstrip mine, Rosebud County, Mont., and the other the 78-foot bed of the Wyodak mine, Cambell County, Wyo. Figures 4 and 5 illustrate the thickness of the beds and the methods of mining in these spectacular operations.

Chemical Method for Estimating Fusain

A method for estimating the fusain content of coal has technical importance because this constituent, which is present in varying amounts in most coals, has been found to affect their hydrogenation and carbonization

11/ Storch, H. H., Hirst, L. L., Fisher, C. H., and Sprunk, G. C., Hydrogenation and Liquefaction of Coal. Part 1. Review of Literature, Description of Experimental Plant and Liquid Phase Assays of some Typical Bituminous, Subbituminous, and lignitic Coals: Bureau of Mines Tech. Paper 622, 1941, 110 pp.

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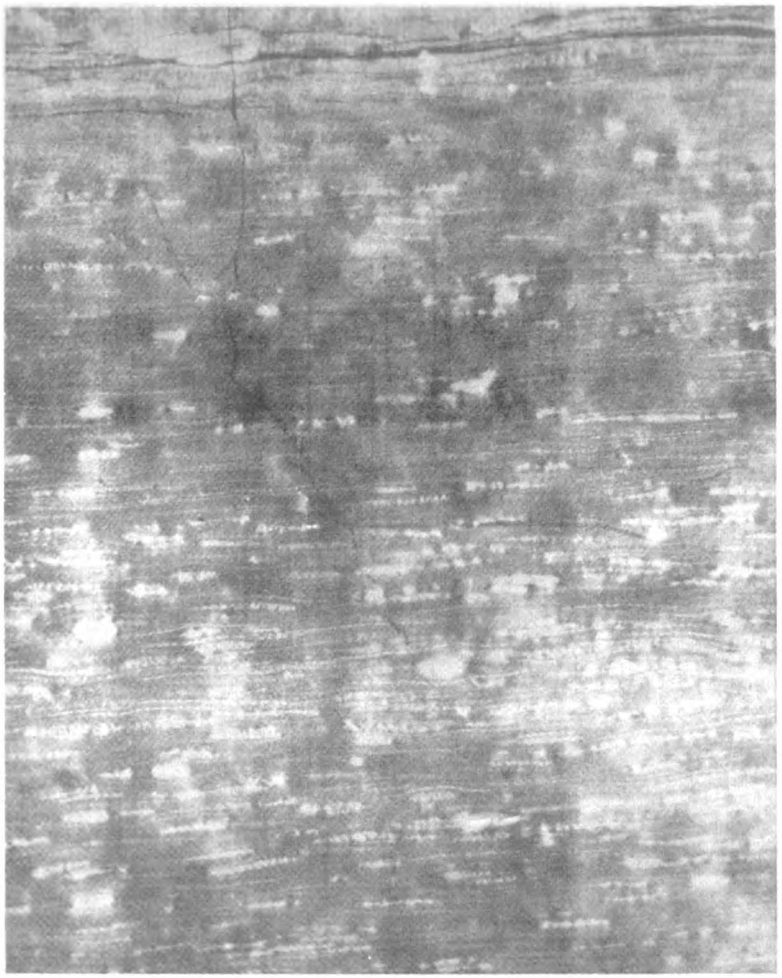

Figure 1.- Type of plant structure observed in coal formed from coniferouslike plants. X 200.

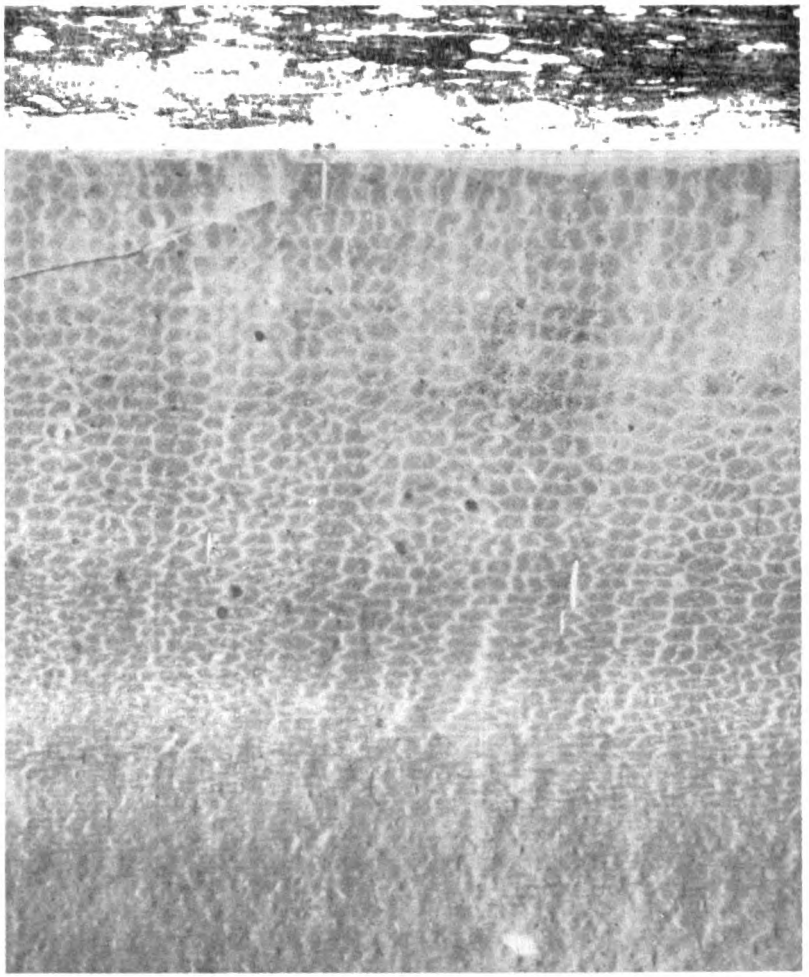

Figure 2.- Type of structure observed in coal formed from lycopod plants. X 200.

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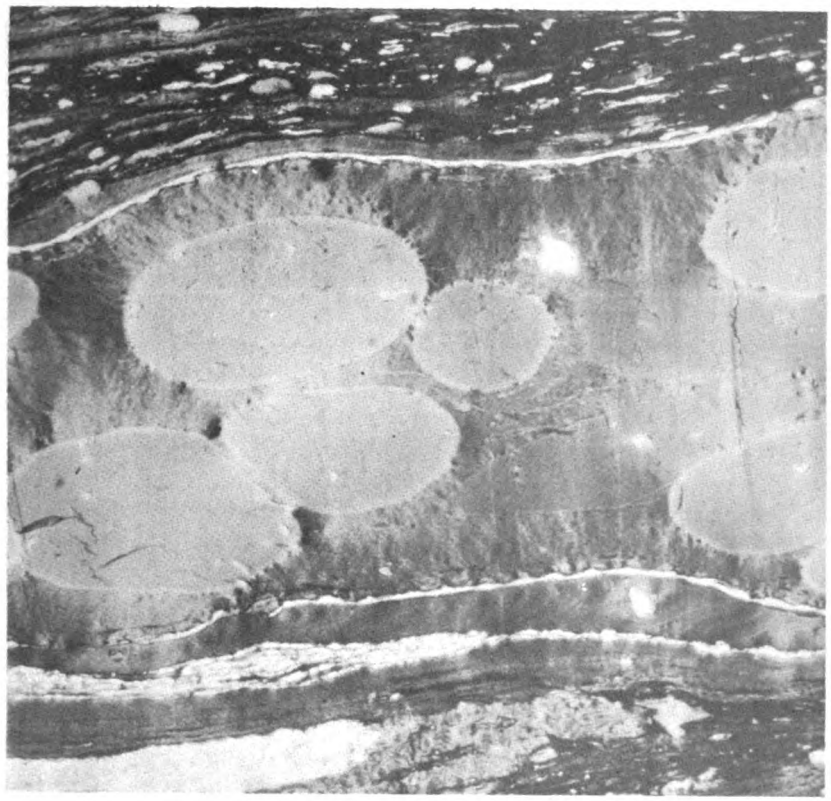

Figure 3.- Remains of gum ducts (sometimes called rodlets) associated with cycadophyte remains in coal. X 200.

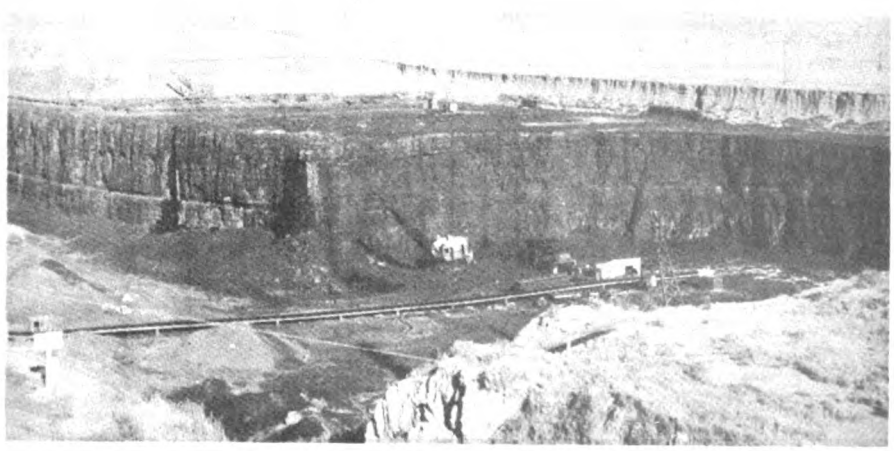

Figure 4.- Mining the thick Roland Smith bed coal, Wyodak mine, Wyoming.

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properties. Of the several methods proposed for quantitative determination of fusain, a chemical method developed at Pennsylvania State College[12] offers certain advantages in that the procedure requires no expensive equipment or specially trained operator. In the Bureau of Mines study of the hydrogenation and carbonization properties of coal, the quantity of fusain in the coal, along with the other microscopical constituents, is determined petrographically; therefore, opportunity was afforded to compare the accuracy of the fusain determination by the petrographic and the chemical method.

In brief, the chemical method consists of oxidizing the coal sample for 2, 3, and 4 hours with nitric acid (8 normal) at boiling temperature. The treated coal is then digested with alkali solution, the oxidized portion of the coal reacting with the alkali to form a soluble humate solution. The insoluble residue, consisting of unoxidized fusain and the acid-insoluble portion of the ash of the coal, is filtered from the solution and dried at 105°C., and the fusain is determined from the loss on ignition. The percentage of fusain in the coal upon the dry, ash-free basis is determined by plotting the amount of unoxidized fusain against the time of digestion, drawing a curve through the points, and extrapolating the straight portion of this curve to zero time.

Table 3 compares the results of the fusain determination on several coals of varying type and rank, using the petrographic and the chemical methods of estimating the fusain content. Inspection of this table shows that good check results are obtained by the two methods.

Volumetric Determination of Sulfur in Coal

Rapid volumetric methods of determining sulfur in coal are being investigated by Committee D-5, American Society for Testing Materials. As one step in this study, several organizations (including the Bureau of Mines) made cooperative laboratory tests on four samples of coal, using three volumetric methods, namely, the sodium rhodizonate, tetrahydroxyquinone, and benzidine methods. Gravimetric determinations were made also by the standard A. S. T. M. bomb-washing and Eschka methods. The results of tests by the Bureau of Mines laboratory show that sulfur in bomb washings can be determined satisfactorily by the sodium rhodizonate and tetrahydroxyquinone methods but that the benzidine method gives erratic results.

12/ Fuchs, Walter, Gauger, A. W., Hsiao, C. C., and Wright, C. C., The Chemistry of the Petrographic Constituents of Bituminous Coal. Part I. Studies on Fusain: Pennsylvania State College, Mineral Industries Exper. Sta. Bull. 23, 1938, pp. 24-27.

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TABLE 3. - FUSAIN CONTENTS OF COALS EXAMINED

Sample	Rank	Bed	Mine	County
Fusain (hand picked)	—	Pittsburgh	Bruceton	Allegheny
Do.	—	Lower Kittanning	Indian Creek No. 1	Fayette
Do.	—	Beckley	Winding Gulf No. 1	Raleigh
Splint	High-volatile A bituminous	Coalburg	Silush	Boone
Do. (pure)	do.	High Splint	Closplint	Harlan
Do.	Low-volatile bituminous	Beckley	Winding Gulf No. 1	Raleigh
Bright	Subbituminous B	Monarch	Monarch No. 45	Sheridan
Do.	Low-volatile bituminous	Beckley	Winding Gulf No. 1	Raleigh
Anthraxylon	do.	do.	do.	do.
Cannel	do.	do.	American Fire Clay & Products Co.	Mahoning

TABLE 3. - FUSAIN CONTENTS OF COALS EXAMINED CONT'D.

State	Coal Laboratory No.	Proximate analysis, dry-coal basis			Fusain, percent		
		Volatile matter, percent	Fixed carbon, percent	Ash, percent	Determined by oxidation method		Determined petrographically
					Test 1	Test 2	
Pennsylvania	B-24646	13.9	77.7	8.4	86	—	90
do.	B-29843	9.1	85.1	5.8	84	84	90-95
West Virginia	B-26584	10.1	86.6	3.3	89	—	90
do.	B-33152	42.1	55.6	2.3	1.4	1.9	2
Kentucky	B-27382	28.9	61.7	9.4	.6	.8	2
West Virginia	B-12641	16.9	80.9	2.2	2.1	2.3	4
Wyoming	B-34792	42.8	52.8	4.4	.3	—	1
West Virginia	B-12640	17.7	78.6	3.7	6.9	7.5	7
do.	B-26583	20.2	78.8	1.0	.4	—	Less than 0
Ohio	B-34393	40.6	43.2	16.2	1.2	—	Less than 1

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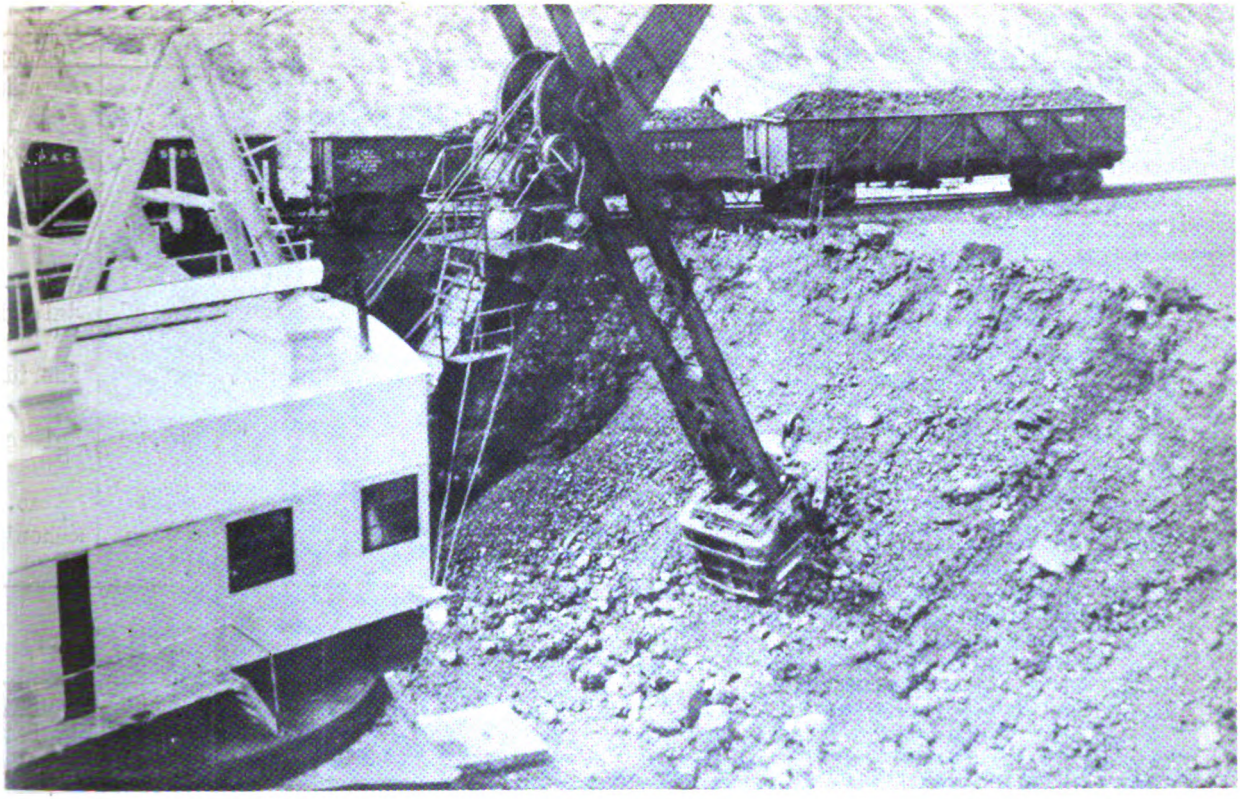

Figure 5.- Mining the 26.8-foot bed of the Colstrip mine, Rosebud County, Mont.

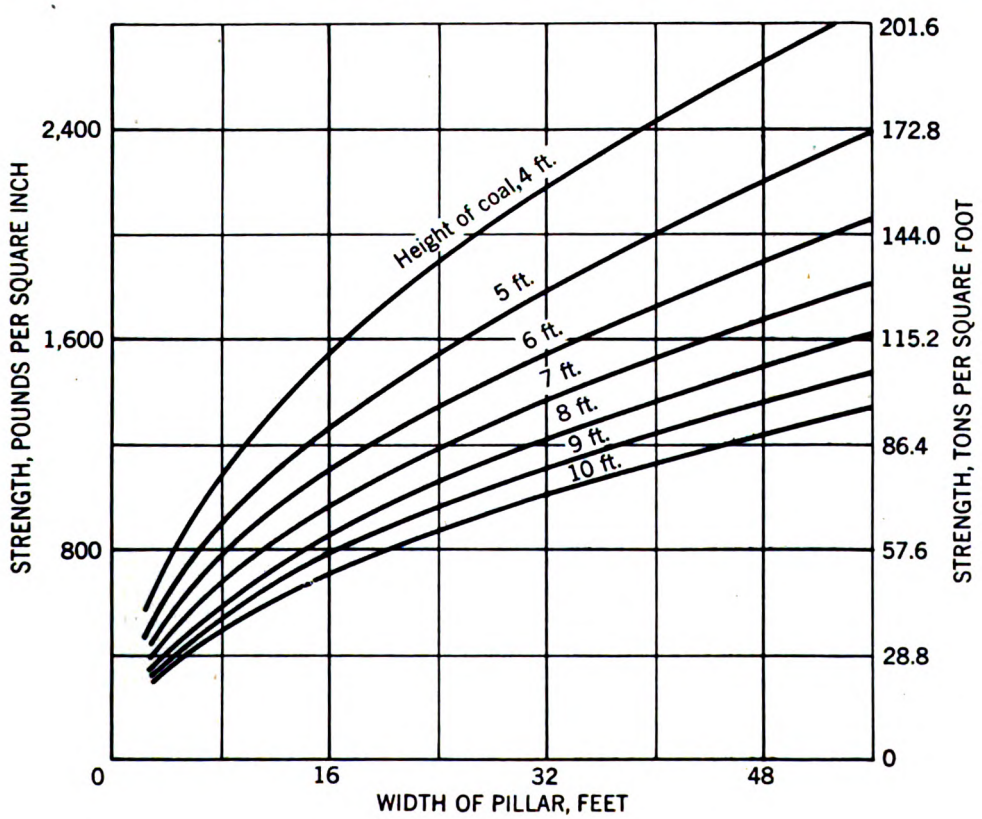

Figure 6.- Strength of square pillars in the Pittsburgh coal bed, computed from equation 5.

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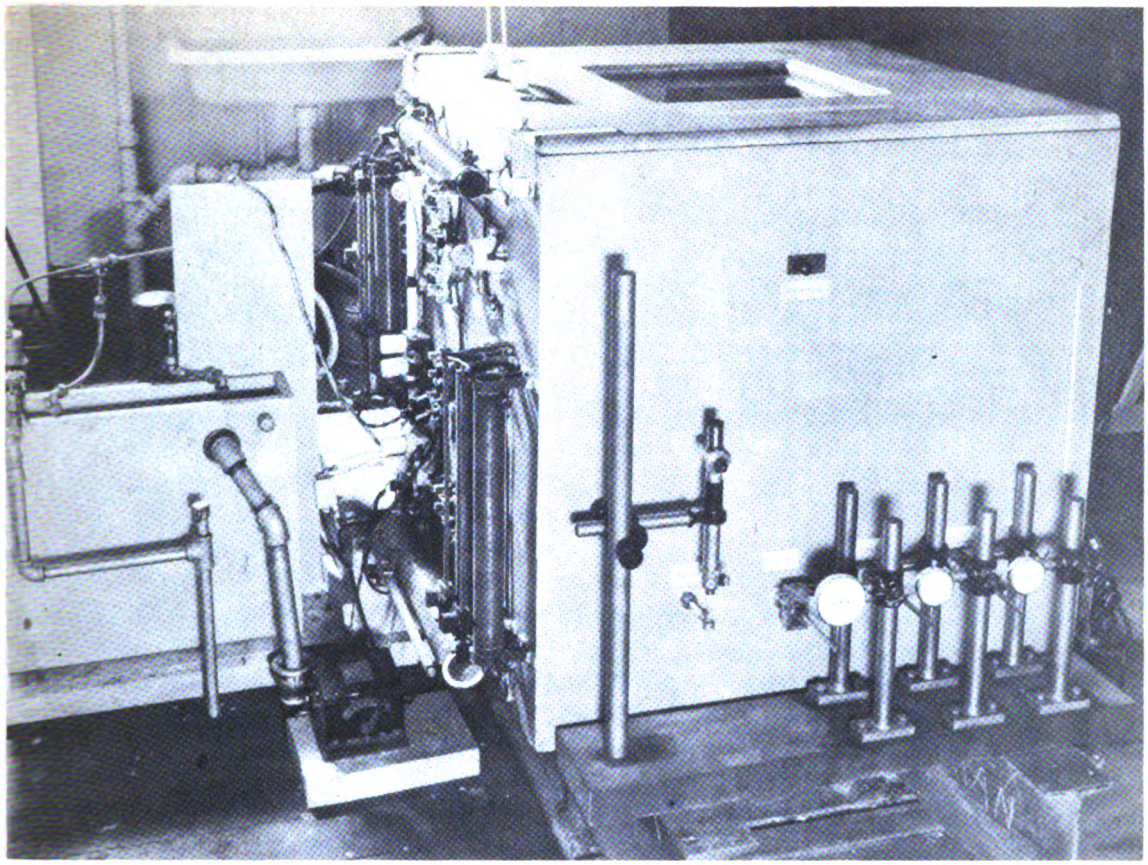

Figure 7.- Air-conditioned cabinet; view showing electrical controls and instruments for measuring rock expansion.

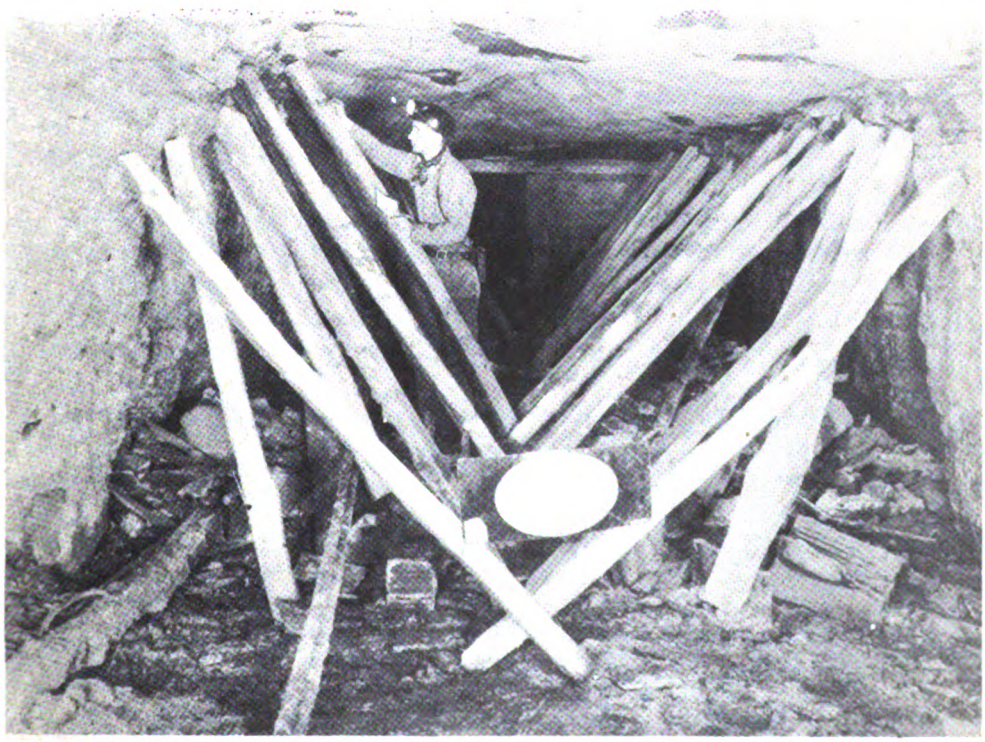

Figure 8.- Posts placed in Crucible mine for test.

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COAL MINING

Experimental Coal Mine

Strength of Small Pillars in Pittsburgh Coal Bed

During the year tests of pillars of coal formed in place from the Pittsburgh bed in the Experimental coal mine[13] were extended to include variations in height of pillars.[14] Correlation of the data led to a general mathematical expression for the strength of square pillars of different lateral dimension and height. Application of this expression is made best through use of curves constructed from it; figure 6 is a sample. From this figure, one can read the unit strength of square pillars of different sizes over a wide range of thickness of bed.

Causes of Falls of Mine Roof

Mine roofs that normally are considered to be self-supporting frequently suffer excessive disintegration during the spring and summer. Methods of combating this trouble include guniting, painting with heavy coal-tar-base paints, and cooling the intake air during the warmer months. To study the cause of these roof falls, apparatus was devised and constructed for obtaining the following information on specimens cut from a coal bed or from the roof strata overlying it: (1) Expansion caused solely by increase in temperature; (2) effect of alterations in humidity of the air, both with and without accompanying changes in temperature, the air being kept below saturation at all times; (3) effect of wetting in a number of ways; (4) absorption of moisture; and (5) mechanical strength and allied properties under varying conditions. The principal item of equipment was an air-conditioned cabinet in which small changes in the length of specimens coincident with any desired change in atmospheric conditions therein could be measured accurately. Figure 7 is a view of this cabinet and part of its control equipment.

Tests were made of specimens cut from the Pittsburgh Coal bed and from two coal and three "slate" (carbonaceous shale) strata overlying it. Some specimens were tested as the materials occur in the mine; others were coated with coal-tar-base paint and with a mixture of sand and cement. As a result of the tests to date, the following conclusions are drawn:

1. The two coals that contain only normal ash have moderately high coefficients of thermal expansion, and the coefficient normal to bedding is 50 percent greater than parallel thereto. The third coal has a high ash content because of slaty inclusions, and its properties are modified by this. The coals respond only slightly, if at all, to changes in humidity, wetting, or immersion in water.

13/ Greenwald, H. P., The Central Experiment Station of the Bureau of Mines: Steel City News, vol. 10, No. 3, March, 1941, pp. 22-26.

14/ Greenwald, H. P., Howarth, H. C., and Hartmann, Irving, Progress Report: Experiments on Strength of Small Pillars of Coal in the Pittsburgh Bed: Bureau of Mines Rept. of Investigations 3575, 1941, 6 pp.

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2. The slates have low coefficients of therman expansion, and the coefficient normal to bedding is twice that parallel thereto. The slates are remarkably sensitive to changes in humidity and expand rapidly when the humidity is raised. Wetting causes sudden expansion and usually disintegration. The initial dryness of the slates is an important factor in their behavior.

3. Protective coatings reduce expansion caused by increase in humidity; this reduction is 75 to 95 percent in different instances, and one may assume corresponding reduction in the internal stresses that cause disintegration.

The investigation will continue to obtain information on the behavior of a wider variety of rocks and to develop a satisfactory explanation of their behavior based upon sound principles of physics and chemistry.

Subsidence of Highway Caused by Mining Coal Beneath

Subsidence resulting from removal of coal beneath highways has, on various occasions, caused damage ranging from a minor unevenness of surface to complete impassability. At least one State has specific legislation defining responsibility for maintenance of highways over coal mines. An opportunity was offered for detailed study of movement of the surface of a paved highway, resulting from the extraction of coal in two different mines that it crossed. As a result of the investigation,15/ it is evident that damage to any given road by subsidence resulting from coal mining and the effect on traffic during subsidence depend on: (1) Nature, amount, and speed of traffic; (2) nature and type of construction of pavement; (3) nature of strata immediately underlying pavement; (4) nature of all strata intervening between pavement and mine workings; (5) thickness of strata between pavement and mine workings; (6) thickness of coal removed; and (7) method and completeness of mining.

Decay of Mine Timbers

From time to time, mine officials have advanced the opinion that rock dust causes more rapid decay of timber in mines. If true, this is an important matter because application of rock dust in coal-mine passageways is the accepted method of combating explosions of coal dust. During the year, there was completed an extended investigation16/ of the relative decay of a number of different species of wood placed in a little-traveled passageway in a commercial mine; half of the specimens were coated with rock dust, and the other half were not. Figure 8 pictures some of these in the mine. The specimens were left in the mine 18 months. The results did not show

15/ Maize, E. R., Thomas, Edward and Greenwald, H. P., Studies of Roof Movement in Coal Mines: 4. Study of Subsidence of a Highway Caused by Mining Coal Beneath: Bureau of Mines Rept. of Investigations 3562, 1941, 11 pp.

16/ Maize, E. R., Scheffer, T. C., and Greenwald, H. P., A Study of Timber Decay in the Crucible Mine of the Crucible Fuel Co.: Bureau of Mines Rept. of Investigations 3544, 1941, 17 pp.

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definitely that rock-dusted wood decayed faster than non-rock-dusted, although there were some indications that might support such a conclusion. It was decided that additional tests were needed to settle the question, and these are now in progress.

Dust in Coal-Mine Atmospheres

A study of pulmonary diseases in the mining industry[17] showed that 6 percent of hard-coal miners had pulmonary tuberculosis compared with 2 percent of the adult male population in the United States and that anthracosilicosis was found in 23 percent of 2,711 employees of three anthracite-mining companies. Indications are that employment in atmospheres containing less than 50 million particles of dust per cubic foot produces a negligible number of cases of silicosis if the quartz content of the dust is less than 5 percent. No single method of dust control is, in general, adequate; therefore, all means of preventing excessively dusty atmospheres must be practiced.

Inflammability Tests

Requests for determination of the inflammability of a wide variety of dusts found in industry continued unabated, and 57 samples were examined during the year. They comprised such diverse materials as coal, coke, dust from shredded metal, rosin, derris root, casein, powdered coffee extract, tapioca starch, insecticides, and catalysts used in the oil industry. In point of origin, they ranged from New York to Alaska.

One large-scale demonstration of the explosibility of coal dust was made at the Experimental coal mine and was witnessed by 450 visitors.

Underground Transportation of Coal

The introduction of mechanical loading in coal mines often necessitates better transportation systems.[18] During the year, a study was made comparing rubber-tired gathering units with animal, conveyor, and rail systems. The study indicates that tonnage per loading-machine shift in mines using the block system has gained where rubber-tired equipment has replaced rail haulage. A new safety hazard arises because of the difficulty of maintaining a definite clearance between the rubber-tired units and the rib and timbers.

Multiple-Shift Mechanical Mining of Coal

The purpose of this investigation of different types of mechanization used in mines under various systems of mining and physical conditions,

17/ Sayers, R. R., Pulmonary Diseases in the Mining Industry: Bureau of Mines Inf. Circ. 7146, 1941, 26 pp.

18/ Toenges, A. L., Some New Developments in Underground Coal Transportation: Paper presented to Southeast Section, Am. Inst. Min. and Met. Eng., at University, Ala., and North Pacific Section, Am. Inst. Min. and Met. Eng., at Tacoma, Wash.

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including pillar extraction by machines, is directed toward reaching conclusions regarding the safest and most economical practices of mining. During the past year, multiple-shift mechanized-mining operations were studied in 15 mines in 7 States.

Inspections of Electric Mining Equipment

The fact that "electricity" was a suspected cause in five of seven recent coal-mine disasters[19] indicates the need for wider adoption of the safety principles[20] and safety (permissible) devices and machines that have been developed as the result of more than 30 years of investigation[21] by the Bureau of Mines.

This investigative work has, as its primary object, the elimination in electric equipment of construction that might cause ignition of gas and coal dust, as well as shock. The investigation of mechanical equipment has the objective of eliminating bodily injury to men working on or around such equipment.

During the past year, 33 approvals[22] of permissible mine equipment were made, bringing the grand total to well over 400 approvals issued since 1914. Approvals of equipment are made after tests are conducted to determine the effectiveness of safety features that must be incorporated in designs.

Diesel Engines Underground

There is widespread interest in the possibility of using Diesel engines for haulage power in mining operations. Studies have continued on the possible hazards involved, in order to develop recommendations and requirements that may serve to establish safe design and safe practices. When a Diesel engine operates underground, the exhaust gases are discharged into the underground atmosphere; therefore these gases may be present in the intake to the engine, even when adequate ventilation is supplied. During the year, studies were made[23] on the effects of operating a Diesel engine when part of the exhaust gas from the engine was mixed with the intake air. These tests showed that, at a given speed, marked increases in the concentration of carbon monoxide in the exhaust occurred at higher power outputs or higher fuel-air ratios. The increase in carbon monoxide was caused partly by the increase in fuel-air ratio and partly by the decrease in the concentration of oxygen in the intake that resulted when exhaust gas was

19/ Ilsley, L. C., Stop-Look-Listen: Mechanization, January 1941, pp. 72-74.
20/ Gleim, E. J. and Brunot, H. B., Mechanized Mining Brings New Electrical Hazards: Bureau of Mines Inf. Circ. 7160, 1941, 11 pp.
21/ Ilsley, L. C., A Quarter Century of Mechanized Mining, Notes on Permissibility: Bureau of Mines Inf. Circ. 7156, 1941, 2 pp.
22/ Gleim, E. J., List of Permissible Mine Equipment Approved During 1940: Bureau of Mines Inf. Circ. 7158, 1941, 4 pp.
23/ Berger, L. B., Elliott, M. A., Holtz, J. C., and Schrenk, H. H., Diesel Engines Underground. II. Effect of Adding Exhaust Gas to Intake Air: Bureau of Mines Rept. of Investigations 3541, 1940, 18 pp.

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added. The concentration of oxides of nitrogen decreased, and the concentration of aldehydes was not affected significantly by the addition of exhaust gas to the intake air.

The decidedly hazardous conditions found when the intake contained more than 1 percent carbon dioxide or less than 19 percent oxygen emphasized the necessity (1) for prohibiting the use of Diesels in sections of a mine or tunnel where it is suspected that ventilation is locally inadequate and (2) for avoiding any "short-circuiting" between the exhaust outlet and the air inlet of the engine.

Further work showed that the operation of Diesels in atmospheres containing methane in concentrations below the inflammable limit resulted in much greater concentrations of carbon monoxide, aldehydes, and oxides of nitrogen in the exhaust gas. Incidental to these studies of hazards, considerable information was obtained on the combustion process in the Diesel engine and on factors influencing Diesel-engine performance.24/

Testing Explosives for Coal Mines

The Explosives Division made physical tests, analyses, and other chemical tests of explosives and blasting devices to establish their permissibility for use in coal mines. The performance requirements, prescribed conditions of use, and fees for testing explosives and blasting devices are presented in Schedule 1C.25/

The active list of permissible explosives and blasting devices now includes the names of 189 explosives and 9 blasting devices.26/ It is encouraging to note that the annual consumption of permissible explosives in coal mines for the first time surpasses the annual consumption of black blasting powder.

Liquid-Oxygen Explosives

Liquid oxygen absorbed on carbonaceous materials makes a high explosive that is useful for certain operations in the open, such as in strip mining for coal. A cooperative investigation27/ with the Pittsburgh Testing Laboratory, supported by the Chile Exploration Co. of New York, showed that

24/ Elliott, M. A., A Rational Basis for Correlating Data on Compression-Ignition Engine Performance at Different Intake and Exhaust Conditions: Presented at summer meeting, Soc. Auto. Eng., at White Sulphur Springs, W. Va., June 1-6, 1941.

25/ Bureau of Mines, Procedure for Applying for Tests Made on All Explosives and Blasting Devices by the Explosives Division of the Bureau of Mines-Prescribed Conditions and Requirements for Permissibility When Used in Coal Mines and Schedule of Fees for the Tests: Sched. 1C, 1939, 13 pp.

26/ Tiffany, J. E., and Gaugler, Z. C., Active List of Permissible Explosives and Blasting Devices Approved Prior to June 30, 1940: Bureau of Mines Rept. of Investigations 3533, 1940, 24 pp.

27/ Denues, A. R. T., Fire-retardant Treatments of Liquid-Oxygen Explosives: Bureau of Mines Bull. 429, 1940, 67 pp.

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the hazards due to the high inflammability of the material can be overcome. Application of phosphoric acid to the absorbent and wrapper rendered these markedly fire-retardant without serious detriment to useful explosive characteristics.

Sheathed Explosives

Sheathed explosives for reducing the risk of ignition in firedamp or coal dust have been developed abroad.[28] Interest of the explosives industry in this country has prompted an investigation during the past year of the effects of sheathing on the gaseous products produced.

Mechanism of Ignition of Firedamp by Explosives

Fundamental research into the mechanism of ignitions of firedamp by explosives, which account for serious mine disasters, was continued to supply basic information to guide the development of safer explosives. Earlier studies[29] suggested that an understanding of the distribution of matter and energy in the products of explosion may form a basis for an explanation of the ignition phenomena.

Calculation of explosion temperatures and products of explosion for typical explosives show that changing the quantity of wrapper changes the oxygen balance, and marked changes in temperatures, pressures, and explosion products are noted. Current work includes an extensive review of the literature on equations of state at high density and the analysis of available compressibility data for gases at high density with extrapolations by the use of theoretical models to explosion temperature and density; comparison of pressures thus calculated with results of other calculations; and a critical examination of the use of the hydrodynamic theory to calculate rates of detonation.

Fires in Anthracite Mines

Laboratory work was continued on the causes, behavior, and control of mine fires. Studies were made on the rate of oxidation of anthracite, the composition of the products of gaseous oxidation and distillation, and the change in composition of these gaseous products caused by external factors, particularly by bacteria. The composition of mine-fire atmospheres has been used to determine when fires have been extinguished and to estimate the activity of unseen fires. One important factor that may modify the composition of a mine-fire atmosphere is bacterial action, and due allowance must be made for this factor before any conclusions are drawn about the activity of an unseen fire. Numerous tests of soils and mine waters from various sources showed that most of these sources contained bacteria that have the

28/ Breyre, Ad., A Twenty Years' Survey of the Use of Sheathed Explosives in Belgium: Bureau of Mines Rept. of Investigations 3530, 1940, 10 pp.

29/ Gerhard, S. L., Holtz, J. C., and Huff, W. J., Recent Researches by the Bureau of Mines on the Ignition of Firedamp by Explosives: Bureau of Mines Rept. of Investigations 3464, 1939, 12 pp.

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faculty of oxidizing hydrogen to water vapor and carbon monoxide to carbon dioxide. During the year, an investigation was made on the effect of acidity and alkalinity on the growth and activity of these bacteria.[30] It was found that the bacteria could function in mediums showing a wide range in acidity and alkalinity - that is, from pH values of 3.0 to 11.0. The pH value of the mediums that react tend to approach the neutral point as the oxidation of hydrogen and carbon monoxide proceeds toward completion. Measurement of rates of oxidation[31] of anthracite in air at temperatures from 1500° to 3500° C. showed that for sizes larger than 20-mesh the rate is directly proportional to the superficial area. For sizes smaller than 20-mesh, however, the rate increased more slowly than the surface area increased and appeared to reach a maximum beyond which further subdivision of the particles had no effect.

PREPARATION OF COAL

Mechanical Cleaning of Coal

In coal fields of Washington[32] and Alabama, nearly 70 percent of the coal that is mined is cleaned mechanically. Where wet washing is employed, the cleaned coal is discharged from the preparation plants in a saturated condition, and the rate at which it drains after reaching storage bins or railroad cars is important to both producers and consumers.

Drainage Characteristics of Alabama Coals

Results have been reported[33] on a project, undertaken in cooperation with the University of Alabama, to evaluate the relative importance of the various factors that affect the rate of drainage of washed coal.

Relative surface area, as calculated from screen analysis, proved to be an important factor. The removal of fines from washed slack coal resulted in additional lowering of the moisture by 3 or 4 percent by the time the washed coal was loaded at the mine.

Activated Carbon from Coal Refuse from Washeries

Activated carbon is used in water purification[34] for the removal of tastes and odors. An investigation has shown[35] that the high-carbon

30/ Jones, G. W., and Scott, G. S., Effect of Hydrogen-Ion Concentration on the Growth of Hydrogen and Carbon Monoxide Bacteria: Bureau of Mines Inf. Circ. 7133, (1940), 5 pp.

31/ Scott, G. S., and Jones, G. W., Effect of Particle Size on the Rate of Oxidation of Anthracite: Bureau of Mines Rept. of Investigations 3546, 1941, 15 pp.

32/ Yancey, H. F., Geer, M. R., Daniels, J., Snyder, N. H., Swingle, R. J., Cooper, H. M., and Abernethy, R. F., Analyses of Washington Coals, Supplement to Technical Paper 491: Bureau of Mines Tech. Paper 618, 1941, p. 3.

33/ Gandrud, B. W., and Coe, G. D., Drainage Characteristics of Alabama Coals: Bureau of Mines Rept. of Investigations 3563, 1941, 27 pp.

34/ Broderick, S. J., Carbonaceous Cation and Anion Exchangers in Water Treatment: Bureau of Mines Rept. of Investigations 3571, 1941, 14 pp.

35/ Broderick, S. J., and Hertzog, E. S., Activated Carbon from Coal Refuse for Water Purification: Bureau of Mines Rept. of Investigations 3548, 1941, 27 pp.

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fractions of mine refuse can be activated by heating to 750°-950° C. in steam or by the zinc chloride method. A good commercial grade of activated carbon can be made from a fraction of the high-grade, low-ash refuse, but the activity of the resulting product decreases as the ash content of the coal increases. The degree of activation of the carbons was measured by both the phenol and iodine adsorption tests. The phenol test was shown to be much superior to the iodine test in evaluating the relative worth of the carbon for water purification.

A method of activation in steam was used in which the temperature of activation could be controlled closely and the extent of gasification or burning could be controlled by measuring the volume of the gases given off in the reaction. This method made it easy to stop the activation process at the point where the activity of the product was maximum. The tests showed that changes in the temperature of activation in the range 750°-950°C. had little effect on the activity of the product but that the rate of gasification increased by a factor of about 1.8 for each 50° C. rise in temperature.

Coal-Mine Refuse as a Water Softener

Tests indicated that the use of Alabama mine refuse as a raw material for making a granular water-softening product is not feasible because of the high loss of fines resulting from the activation treatment.36/ The coal fraction of the mine refuse proved to be more active than the clay fraction as a cation exchanger in softening water, so an activation procedure was developed for coal.

The method of activation of coal that produced the highest exchange capacity was a concentrated sulfuric-acid digestion, followed (after thorough washing) by autoclaving with dilute sodium hydroxide. A product was obtained that had a sodium-exchange capacity of 6,500 grains per cubic foot and a hydrogen-exchange capacity of about 7,500 grains.

Tests showed that the life of the exchanger was virtually indefinite - 38 regenerations caused no appreciable loss in base-exchange capacity.

Steam Drying of Subbituminous Coal and Lignite

In cooperation with the University of North Dakota, large-scale laboratory tests were continued to determine the time required to dry various sizes of lignite with saturated steam by the Fleissner process. Investigations had shown that both the time and the cost of drying should decrease as the size of lignite decreased.37/ These deductions were confirmed in

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36/ Broderick, S. J. and Bogard, D., Carbonaceous Cation Exchangers from Coal and Coal Refuse: Bureau of Mines Rept. of Investigations 3559, 1941, 17 pp.

37/ Parry, V. F., Harrington, L. C., and Koth, Arthur, The Preparation of Stable Nonslacking Fuel by Steam Drying Subbituminous Coal and Lignite: Trans. Am. Soc. Mech. Eng., in press.

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the large-scale tests, which demonstrated that lignite having an average size of 1-1/2 inches can be dried in 25 minutes, thus increasing its heating value from 6,900 to 10,000 B.t.u. per pound. As the heat for drying is transferred from condensing steam by direct contact, these large-scale laboratory tests in all probability compare well with the time required for drying lignite in large commercial autoclaves. Cost estimates indicate a low cost of drying lignite in a plant of commercial size. The saving in freight charges on a haul of moderate length would pay for the cost of drying the lignite.

Table 4 summarizes experiments made to determine the time required to dry different sizes. The improvement ratio referred to in this table is the ratio of the weight of lignite before drying to the weight after drying. It is also the ratio of the heating value of dried lignite to the heating value of raw lignite. Table 5 shows the relationship of improvement ratio to heating value and moisture content of dried lignite produced from raw lignite having 35 percent moisture and a heating value of 7,000 B.t.u. per pound.

STORAGE OF COAL

Oxidation of Coal in Storage and Spontaneous Ignition

Coal has the property of consuming oxygen from the air, even at ordinary outdoor temperatures. Recent studies of this property[38] and the effect of conditions upon the rate of oxidation have brought out many facts that should be considered when coal is to be stored.

The laws governing the rates of oxidation of coal at low temperatures that were discovered in this work explain many of the phenomena observed in studies of spontaneous ignition of large piles of coal.

The rate of oxidation is tripled when the temperature of the coal is raised only 24° F. and is three times faster for 18-mesh than for 1-inch coal. Reducing the percentage of oxygen in the air from its normal value of 20.9 to a value of 3.5 decreases the low-temperature rate of oxidation 67 percent.

Freshly broken surfaces of coal consume oxygen at a high rate, but the rate decreases rapidly. The laws governing this rate of decrease have been determined, so that the rate at any time or extent of oxidation can be predicted with considerable accuracy. For example, a sample of an average coal (fine) 12 hours after crushing consumes oxygen three times as rapidly as it will 2.9 days after crushing.

38/ Schmidt, L. D., Effects of Storage and Oxidation of Coal upon Coking Properties: Iron and Steel Eng., vol. 18, No. 3, March 1941, pp. 64-72.

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TABLE 4. - Drying of lignite by Fleissner process. Summary of experimental results at University of North Dakota, fiscal year 1941.

Average size of raw lignite, inches	Cycle time, minutes			Improvement ratio 3/
	Heating 1/	Cooling 2/	Total	
1.75	90	13	103	1.45
	28	15	43	1.42
	28	10	38	1.41
	28	10	38	1.46
	23	10	33	1.43
	20	10	30	1.43
1.25	75	50	125	1.44
	75	50	125	1.48
	75	40	115	1.48
	75	25	100	1.47
	60	16	76	1.43
	57	11	68	1.46
	24	30	54	1.46
	44	10	54	1.44
	39	15	54	1.42
	36	11	47	1.45
	28	15	43	1.43
	31	10	41	1.46
	30	11	41	1.45
	29	10	39	1.41
	27	10	37	1.44
	19	18	37	1.41
	25	10	35	1.43
	24	10	34	1.45
	24	10	34	1.42
	23	10	33	1.45
	21	12	33	1.41
	15	10	25	1.45
.625	29	10	39	1.41
	22	10	32	1.42
.375	21	10	31	1.44
	17	10	27	1.42

1/ Heating period defined as time before releasing steam pressure; includes preheating time and soaking time.
2/ Cooling period defined as time after steam pressure is released; includes vacuum period.
3/ Improvement ratio = weight ratio.

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TABLE 5. - Relationship of improvement ratio to heating value and moisture content of dried lignite1/

Improvement ratio	Heating value, B.t.u. per lb.	Moisture, percent	Improvement ratio	Heating value, B.t.u. per lb.	Moisture, percent
1.35	9,450	12.3	1.43	10,010	7.0
1.36	9,520	11.6	1.44	10,080	6.3
1.37	9,590	11.0	1.45	10,150	5.7
1.38	9,660	10.3	1.46	10,220	5.1
1.39	9,730	9.6	1.47	10,290	4.4
1.40	9,800	9.0	1.48	10,360	3.7
1.41	9,870	8.3	1.49	10,430	3.1
1.42	9,940	7.7	1.50	10,500	2.5

1/ Calculated, assuming raw lignite has 35 percent moisture and a heating value of 7,000 B.t.u. per pound.

Table 6 shows the average changes in proximate and ultimate analysis of nine coking coals (1/4-inch slack) that were subjected to carefully controlled oxidation. The average time of exposure to air at 211° F. was 4.5 days, which corresponds roughly to 450 days of exposure at ordinary outdoor temperatures. The heating value of the coal decreased regularly with increasing extent of oxidation, whereas the oxygen content of the coal increased regularly.

TABLE 6. - Changes in proximate and ultimate analysis with oxidation of coal

Changes in proximate and ultimate analyses, based upon average for 9 coals oxidized at 211° F. (moisture- and ash-free basis)

Oxygen consumed	percent by weight of coal	1
Days in air at 211° F. (0-1/4-inch coal)		4.5
Decrease in heating value	percent	.69
Decrease in carbon content	percent	.40
Increase in oxygen content	do.	.49
Decrease in volatile-matter content	do.	0.6
Increase in real specific gravity of coal	percent	.905

An apparatus has been built for measuring the total surface - internal plus external area - of samples of coal. This value depends on both the particle size and the porosity of the coal and is very important in studies of the oxidation reaction. The method involves obtaining low-temperature adsorption isotherms, using argon gas. Preliminary tests indicate that the total surface available for adsorption of this gas is 10 to 1,000 times greater than the geometric or external surface of the coal - the factor depends on the rank of coal and the particle size.

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Storage of Subbituminous Coal and Lignite

Proper storage of subbituminous coal and lignite is necessary if slacking and degradation are to be avoided.39/ A typical subbituminous coal from Weld County in the Northern Colorado field was stored under various conditions for 180 days. Part of the sample was exposed to average outdoor weather conditions, another part was stored in a ventilated concrete bin and a third part in a closed concrete bin. Measurements were made of the change in size, the changes in friability properties, and the changes in heating value and chemical properties.

It was observed that when subbituminous coal is stored in a closed bin, having minor variations in temperature and minimized circulation of air, only minor physical and chemical changes occur in the coal during 3 months' storage. The change in average size was 8.3 percent, and the heating value of the coal substance decreased 0.6 percent. During a 35-day period the change of size in a sample stored under similar conditions was only 5 percent, whereas the change in size in a sample stored for the same length of time but in a ventilated bin was 17.0 percent. In contrast to these, a similar sample exposed to the weather changed 75.0 percent in size. During a 20-day period of exposure in a ventilated bin, the friability increased from 16.1 percent to 38.4 percent.

This investigation indicated that, under proper conditions which control the factors influencing moisture change, subbituminous coal can be stored in closed bins for long periods without much degradation. The preferred conditions for storage are: (1) A closed, tight bin having minimum circulation of air; (2) slow rate of change of temperature of the interior of the bin, which allows the coal to adjust to temperature conditions without excessive surface stresses; and (3) low temperatures, if possible, to reduce vapor pressure and evaporation. Under these favorable conditions, the atmosphere in the bin will remain essentially saturated with water vapor. This prevents loss of moisture from the surface of the coal and retards degradation by minimizing its cause. Deterioration of the heating value of the coal by oxidation is less if physical degradation is retarded by proper storage.

UTILIZATION OF COAL

Combustion

Fuel Engineering Service

Consulting service was rendered to many other agencies of the Government on the selection and use of fuels and equipment for burning fuels. Comparative operating costs with different types of fuels were prepared for various new Government projects. Recommendations were made to the War Department on type of equipment, method of operation, and choice of fuel for various army camps. Specifications for coal for the Arctic region were

39/ Parry, V. F., and Goodman, J. S., Storage of Subbituminous Coal in Small Bins: Bureau of Mines Rept. of Investigations 3587, 1941, (in pres).

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recommended. A series of acceptance tests was made on heating plant equipment at five new plants for the regional research laboratories and research center of the Department of Agriculture. At each plant, readjustment and replacement of certain equipment were found necessary.

Acceptance tests of new steam-jet ash ejectors at the Capitol Power Plant showed the necessity of changing the size of the steam nozzles. Detailed studies were made on the preparation of complete specifications for various new boiler plants.

Boiler Feed-Water Conditioning. - Water analyses and resulting recommendations were made for 1,375 samples from various Government plants. A report was prepared on analyses of 9 boiler compounds and 18 boiler scales and sludges for various activities. Acceptance tests were run on 2 new deaerators.

Inspections were made on boilers at three plants on corrosion in a sterilizer and on scaling in the condensers of an air conditioner, and appropriate recommendations were given.

A study and analysis of several sludges were made to determine the cause for frequent valve failures at a hospital. It was found that the failures were caused by an excessive amount of iron oxide, which in turn was due to a condensate of low pH (high acidity).

Smoke Abatement. - Consulting service was given to municipalities and Government plants on the abatement of smoke and fly-ash. A bibliography of references was prepared on the determination of atmospheric sulfur dioxide, the determination of dust fall, and the determination of atmospheric dusts. A discussion was prepared on the methods employed in reducing emission of fly-ash from chimneys.[40]

Removal of Ash as Molten Slag from Pulverized-Coal Furnaces

The general problem involved in determining the flow characteristics of coal-ash slags was outlined in a previous report,[41] and emphasis was placed on the existence of a liquidus temperature during the cooling or heating of these slags. Below this liquidus temperature, slags no longer behave as true liquids having fixed temperature-flow characteristics but instead are greatly influenced by time and by the type and the dimensions of the instrument used in their measurement. Thus determination of the flow characteristics of coal-ash slags below the liquidus temperature (that is, where the slag is an actual mixture of liquid and solid phases) becomes an arbitrary one, and greater difficulty is to be expected in obtaining reproducible data and in utilizing these data. However, a test procedure has

40/ Barkley, J. F., Methods Employed in Reducing Fly Ash Emission from Chimneys, Manual of Ordinances and Requirements: Smoke Prevention Assoc. America, Inc., 1940, pp. 84-91.

41/ Fieldner, A. C., and Rice, W. E., Annual Report of Research and Technologic Work on Coal, Fiscal Year 1940: Inf. Circ. 7143, 1940, 50 pp.

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been devised for this measurement, using a continuously rotating instrument of the Margules type. Although the data are expressed in the absolute units of poises, the determination is actually one of "apparent" viscosity. Thus continuous curves of viscosity may be plotted, the data above the liquidus temperature being absolute and those below the liquidus temperature arbitrary.

New Instruments.[42] - Figure 9 shows the viscometer furnace and the assembly for measuring the density of liquid slags by means of an immersed platinum cylinder.

Figure 10 shows an electrically heated furnace developed for the determination of the A.S.T.M. cone-fusion temperatures in an atmosphere of air. The furnace is similar to that of the viscometer set-up and consists of a 2-inch-diameter carborundum tube, which acts as a resistor. The switches for the multiple transformer and the controls are on the board. This furnace can be used up to 2,900° F., whereas a platinum-resistance furnace should be limited to 2,700° F. The temperature of the cones is given by a thermocouple inserted from the rear, with the junction close to the cones.

Burning Solid Fuels on Traveling Grates

The studies of the burning of fuels on the crossfeed principle - that in which the fuel moves at right angles to the flow of air, - as on traveling grates - has been continued for anthracites and high-temperature coke. All tests are made under close control of the applied conditions (such as air rate and temperature, size of fuel, and formation of fuel bed), and any one factor can be varied while the others are kept constant. The control is such that repeat tests give duplicate results. With any one fuel and fuel condition of size and moisture content, the three operating factors of air rate, air temperature, and temperature of the ignition arch may be varied.

The main burning characteristics determined are (1) the time required for the initial ignition of the surface of the fuel bed, (2) the rate of travel of the plane of ignition to the grates, (3) the rate of gasification of the fuel, and (4) the pressure drop through the fuel bed against time.

Tests[43] of the previous year were concerned with the main principles of the relationship of results to large variation of size, air rate, and temperature of the ignition arch. Sizes of fuel were used that are not burned commercially on traveling-grate stokers. The investigations this year have, in the main, been restricted to commercial sizes - coke breeze and buckwheat sizes of anthracite - and the results of the burnings compare directly with commercial operations.

42/ Reid, W. T., An Electronic-Contacting Galvanometer for Temperature Control, Temperature, Its Measurement and Control in Science and Industry: Reinhold Pub. Co., 1941, pp. 611-616.

43/ Fieldner, A. C., and Rice, W. E., Work cited in footnote 41.

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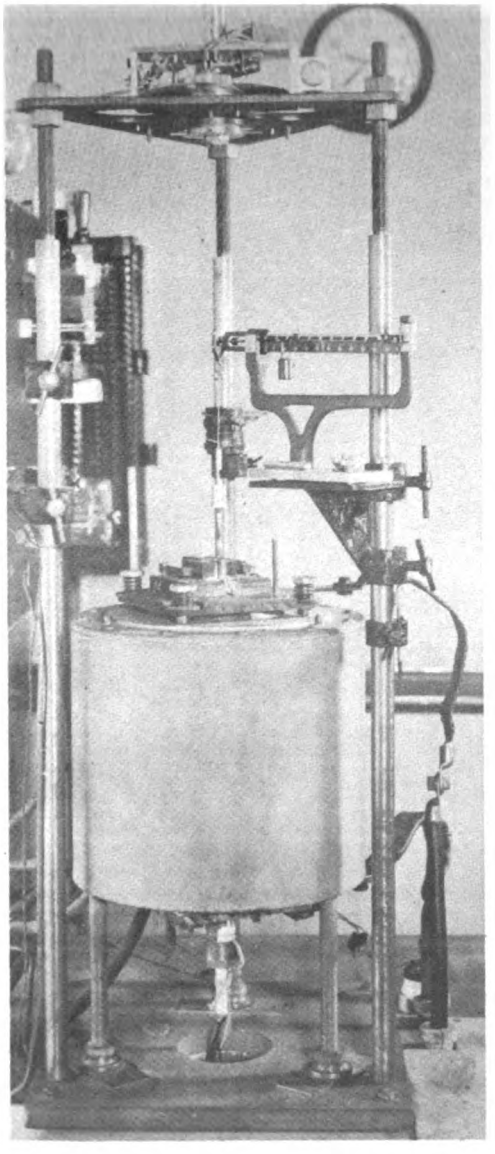

Figure 9.- Apparatus for measuring density of liquid slags, mounted on slag-viscosity furnace.

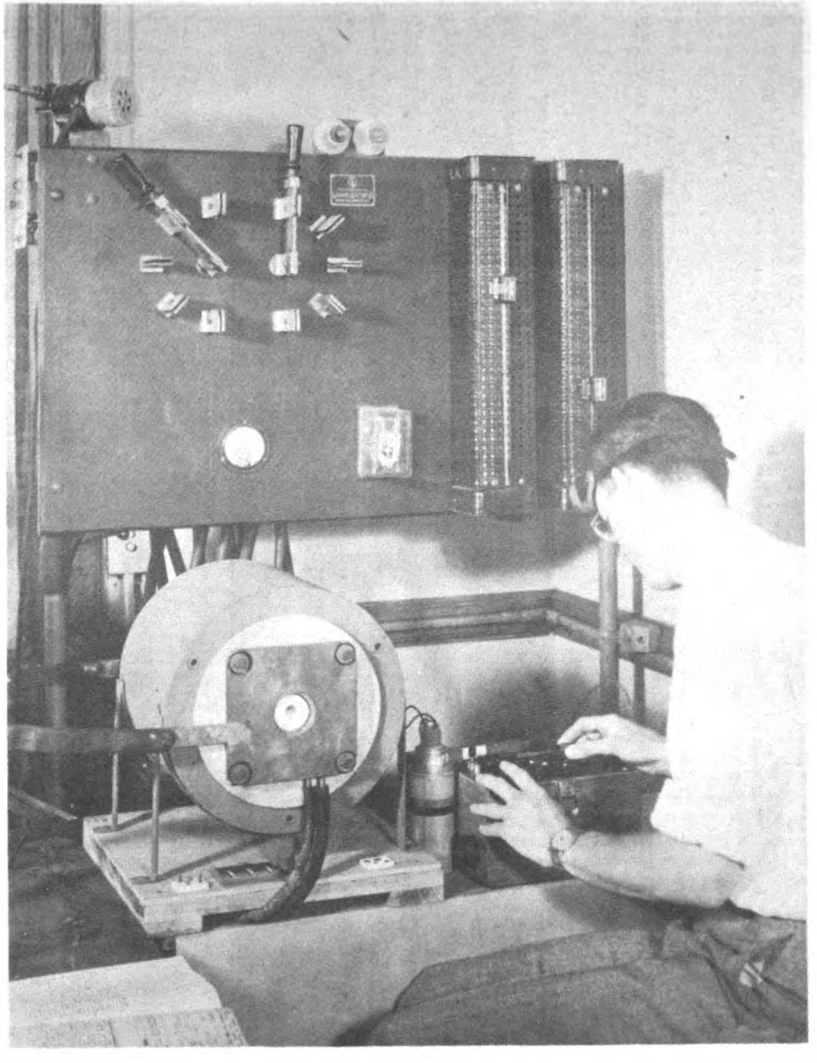

Figure 10.- Carborundum-tube furnace for determination of A. S. T. M. cone-fusion temperature in air.

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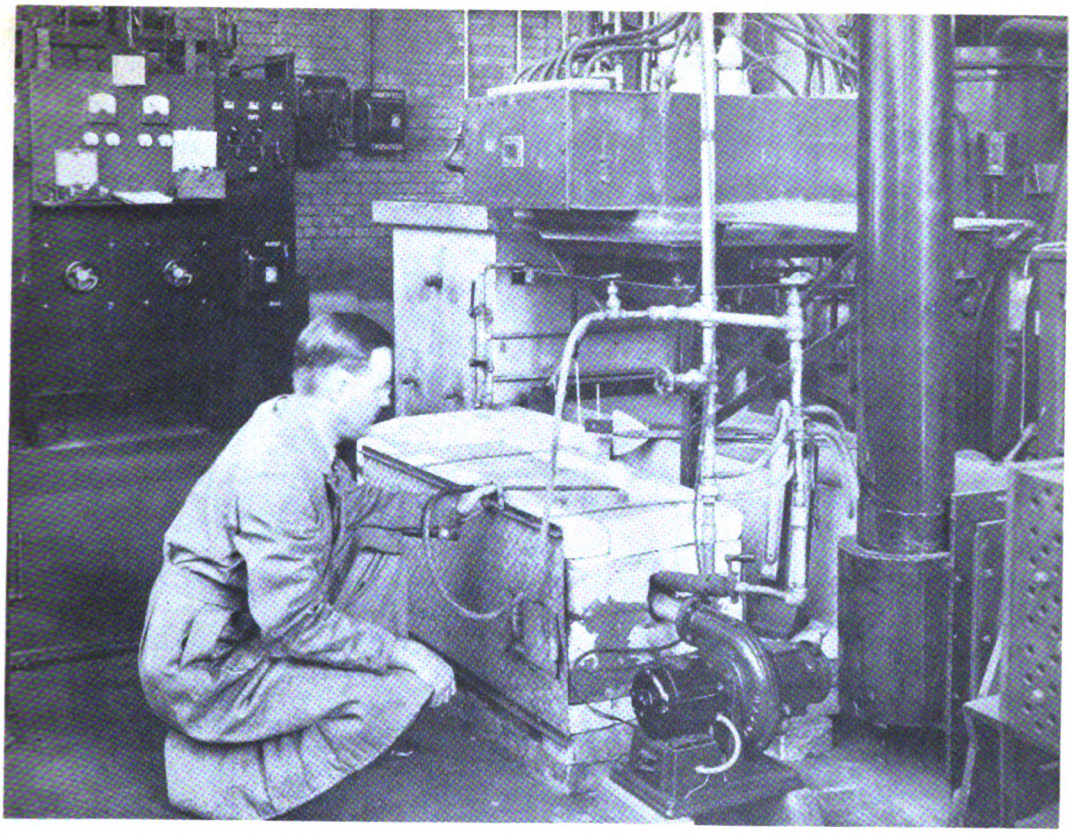

Figure 11.- Air-preheating equipment of crossfeed furnace.

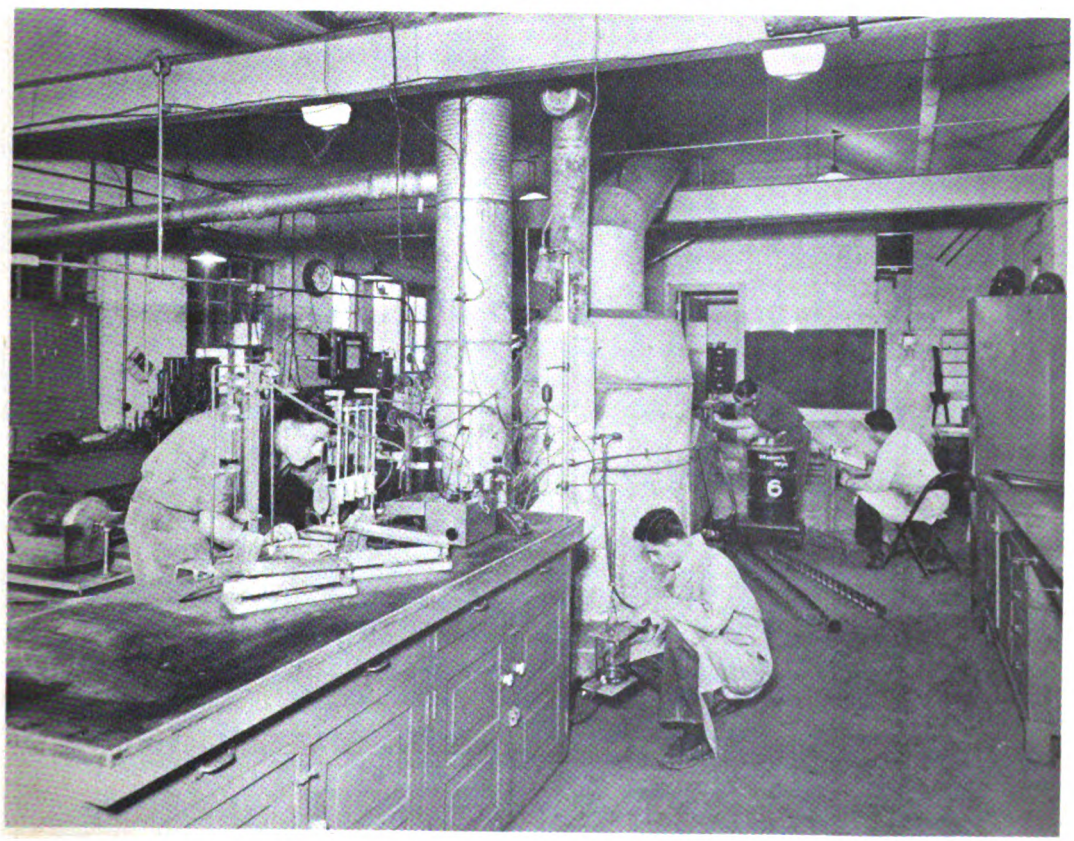

Figure 12.- Experimental domestic stoker.

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Some factors, the effects of which have been studied, are:

1. The effect of the degree of initial ignition on the rate of travel of the plane of ignition through the bed.
2. The effect of varying degrees of preheat on the burning of small anthracite.
3. The effect of secondary air over the bed on the amount of combustible gasified when the quantity of primary air is enough to cause "boiling" of the bed.
4. The effect of the moisture content of the fuel as fired on both types of ignition and on pressure drops through the bed.
5. The effect of size composition of mixed size of fuel, with special reference to the percentage of fines in coke breeze.
6. The effect of the ash content of the fuel; the ash ranged from 5 to 70 percent.
7. The effects of the addition of small amounts of a few chemicals.

The variation in resistance to the flow of air through the fuel of a chain grate in relation to its position at its travel is all-important, as also are the relations of the rates of ignition and of burning to the flow of air. The methods of test used are well-adapted to making such studies and to correlating experimental data with theory.

The degree of ignition, rate of burning, and resistance to air flow of the fuel change along the length of a stoker, but with constant operation are fixed at any one position. From the test data, a complete picture of the conditions of the fuel bed along its length can be developed for a defined air control, such as constant air pressure below the grate bars.

Apparatus. - The apparatus described in previous reports has been entirely satisfactory and its deterioration not high, considering the unfavorable effects of the daily heatings and coolings on the refractories and carborundum parts.

An air preheater has been added, by which the temperature of the primary air can be increased beyond the maximum required (400°F.). Figure 11 is a general view; the refractory gas-heated furnace is in the foreground and connects to one end of the tubular heat exchanger in the rear.

Combustion of Subbituminous Coal and Lignite in Domestic Equipment

The object of this investigation was to study the performance of subbituminous coal and lignite in heaters, furnaces, and stokers now being used for burning these fuels and to develop improved methods for burning these noncaking coals in small equipment that furnishes domestic services. Figures 12 and 13 show some of the equipment used in these studies. The experimental work of this year included: (1) Tests to determine the performance of different sizes of subbituminous coal in a stock-model domestic stoker, which permitted using either of two types of retorts and either of two types of screw worms for feeding coal to the retort; (2) the performance

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of different sizes of coal in space heaters; and (3) the performance of a small automatic stoker for heating service water. Experimental development was conducted on new furnaces for burning noncaking coal with gravity feed stokers and for burning coal dust in suspension. Coal from the Northern Colorado field was used for the tests.

Investigations conducted during the previous year had shown that the principal difficulties encountered when low-rank coals are burned in domestic appliances are caused by the dust included in most prepared sizes.44/ These coals do not coke in the fuel bed; consequently the fine sizes are reduced in size by combustion and are free to move, resulting in beds of variable resistance and producing much fly-ash. During the current year, it was demonstrated that stokers and other appliances perform best if the size range of the fuel is limited and if dust is removed before firing. Better performance in stokers was noted with coals having sizes smaller than 1 inch. Several explosions were experienced when 3/4- by 1-1/2-inch size was used, caused by dust formed by degradation in the worm, whereas no troubles were encountered when the 1/8- by 3/4-inch size was burned. The experimental work of the current year also showed that retorts having more and smaller tuyeres, some being on the outside, improve the performance of subbituminous coal in domestic stokers.

A small, commercial, automatic anthracite stoker for service hot water was adapted to use subbituminous coal. This stoker was tested for 8 months, and when improvements were added it operated for 1 month without attendance on 1/16- x 3/8-inch coal. An average of 8 pounds of coal a day was consumed to heat the service water for the laboratory.

An investigation was begun on the degradation of subbituminous coal in stoker worms. The object of this work is to determine the factors that affect movement and degradation of coal in small, mechanical stoker worms and the effect of these factors on physical properties and on distribution of the coal at the retort. Table 7 shows the type of data obtained in this investigation.

Coke and Gas Making

A survey of recent progress45/ in making of coke and gas showed that only 193 byproduct coke ovens were completed in 1940, whereas 286 were completed in 1939.

44/ Parry, V. F., and Segur, R. D., Performance of Subbituminous Coal in a Typical Underfeed Domestic Stoker: Bureau of Mines Rept. of Investigations 3557, 1941, 18 pp.

45/ Fieldner, A. C., Processing and Carbonization of Coal: Min. and Met., vol. 22, 1941, pp. 114-115.

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TABLE 7. - Degradation of subbituminous coal in a domestic stoker. Distribution of sizes emerging from retort, percent 1/

Screen size, inches 2/	1.05 x 1.5	0.742 x 1.05	0.525 x 0.742	0.185 x 0.525	0.093 x 0.185	0.0 x 0.093	Total	Average size	Degradation percent
Original size:									
A	100						100	1.27	
B		100					100	.895	
C			100				100	.633	
D				100			100	.355	
E (modified pea)	22.4	32.8	23.5	15.0	2.8	3.5	100	.786	
Rear quarter:									
A	1.4	4.0	4.0	7.5	3.3	4.2	24.4	.463	
B		4.8	5.9	7.7	2.6	2.8	23.8	.471	
C			7.6	12.8	1.5	1.7	23.6	.407	
D				21.5	1.4	1.2	24.1	.328	
E	.6	3.8	4.9	9.3	3.6	4.7	26.9	.420	
Front quarter:									
A	2.8	7.9	8.1	3.7	.5	.2	23.2	.741	
B		8.9	9.1	3.4	.1	.1	21.6	.694	
C			13.0	10.8	.1	.1	24.0	.500	
D				23.8	.2	.2	24.2	.347	
E	1.5	7.2	6.4	5.3	.2	.4	21.0	.681	
Right quarter:									
A	1.6	6.5	4.9	5.6	3.3	5.6	27.5	.498	
B		7.5	6.9	5.4	2.2	4.4	26.4	.511	
C			9.4	11.3	1.5	3.0	25.2	.409	
D				21.5	1.2	1.2	23.9	.331	
E	.8	5.1	5.5	6.8	2.7	5.3	26.2	.462	
Left quarter:									
A	2.6	7.5	6.8	6.3	1.2	.5	24.9	.671	
B		12.7	9.2	5.7	.4	.2	28.2	.684	
C			14.8	12.0	.1	.3	27.2	.504	
D				27.1	.5	.2	27.8	.349	
E	1.5	6.4	7.0	9.1	1.1	.8	25.9	.595	
Total:									
A	8.4	25.9	23.8	23.1	8.3	10.5	100	.589	54
B		33.9	31.1	22.2	5.3	7.5	100	.589	34
C			44.8	46.9	3.2	5.1	100	.456	28
D				93.9	3.3	2.8	100	.339	4.5
E	4.4	22.5	23.8	30.5	7.6	11.2	100	.531	32.4

1/ Original weight of sample, approximately 250 pounds.
2/ Square mesh.
3/ Pounds of coal per revolution of worm: C = 0.391; D = 0.408.

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The demands of national defense no doubt will result in an increase in this figure for 1941. The increased demand for pyridine for medicinal and fabric-waterproofing compounds led to the recovery of crude pyridine from saturator bath liquors at several byproduct plants. The first commercial plant in the United States for the production of ammonium thiocyanate crystals was put into operation. Other improvements in commercial practice included use of semicontinuous recovery of light oil, continuous sulfate driers, and the treatment of coal with oil to increase the density of charge in the coke oven.

The present need for industrial preparedness has aroused new interest in the availability of coke in the West. This interest in the coke supply arises from consideration of the needs in electrochemical and electrometallurgical processes using electricity made at the new dams, proposed blast and open-hearth furnaces in the West, and the new munitions plants.

The possibilities of using the coking coals of Washington have been covered in an extensive report analyzing the available supplies of Washington coking coals, the quality and properties of the coke produced, and the technologic and economic factors involved in the manufacture of coke on the West coast.46/

The results of all the investigations and tests confirm the conclusion that the coals from Pierce County, Wash., can be coked successfully in byproduct ovens to produce domestic, smelter, foundry, and metallurgical coke suitable for ferrous smelting in blast furnaces, as well as coke suitable for the manufacture of producer and water gas. Coke produced from these coals can be expected to have a high ash content and low sulfur content (0.6 percent) and apparently will cost $7 or $8 a ton.

Survey of Carbonizing Properties of American Coals

In cooperation with producers of coking coals, large samples representative of the coal beds are taken and subjected to a large number of tests to obtain thorough knowledge of the properties of the coals. Both producers and consumers benefit by the information obtained, and the Nation is served as the range of coals suitable for carbonization is extended. The reserves of best coking coals tend to be conserved by the attention given to their especially valuable coking properties.

To evaluate fully a coal for the gas and coke industries, it is necessary to know not only the yield and quality of the carbonization products but also the effect of storage on coking properties and whether or not the coal expands enough to damage walls of coke ovens.

46/ Daniels, J., Beehive and Byproduct Coking in Washington: Bureau of Mines Rept. of Investigations 3551, 1941, 77 pp.

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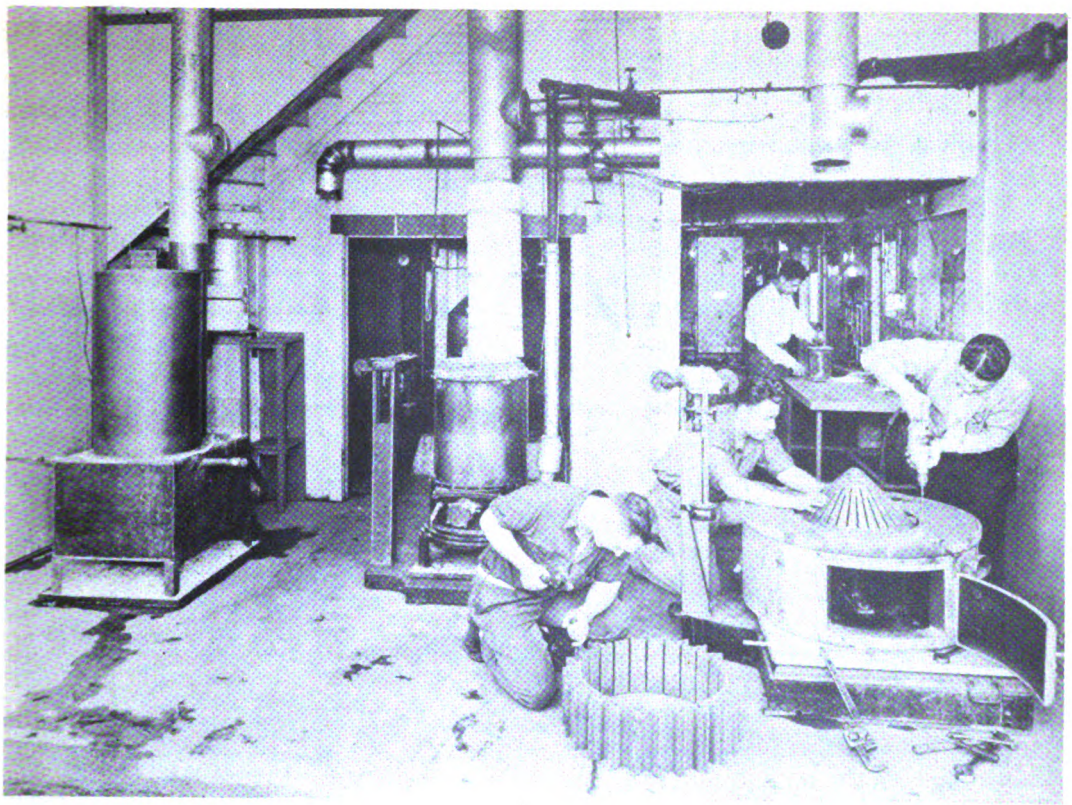

Figure 13.- Furnace-testing laboratory.

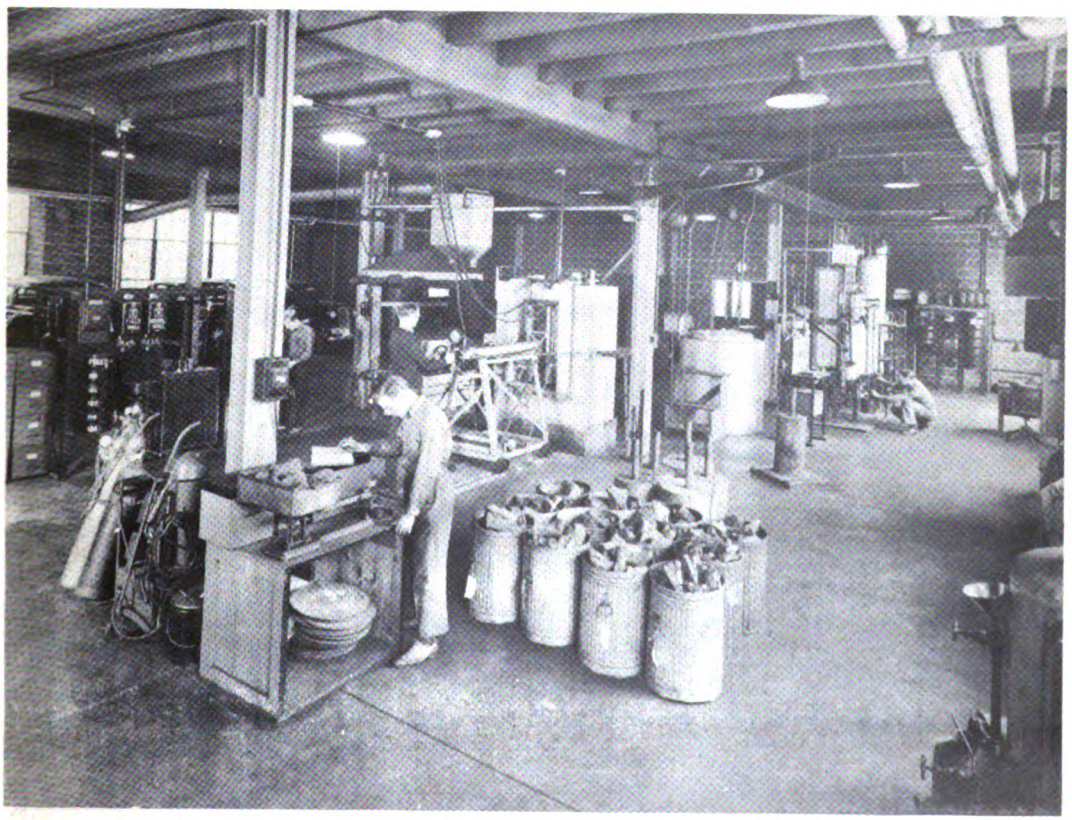

Figure 14.- Coal-carbonization laboratory.

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Technical papers published during the year[47] give complete carbonizing properties of three coals and their petrographic composition.

Large scale (BM-AGA) carbonization tests were completed on four new coals during the year by methods developed previously.[48] A general view of the equipment used is shown in figure 14.

The fact that three of these coals were from Pacific or Midwest States indicates an increasing trend toward the development of gas and coke industries in these regions without the use of eastern coal. Coals 65 and 66 were from Washington, coal 67 from Kentucky, and coal 68 from Oklahoma. Table 8 gives the sources and analyses of the four coals and of other coals that were blended with them to improve the properties of the cokes produced. Coal 65 (Washington) contains 11.4 percent ash, which is high for a coal to be used for making metallurgical coke; however, this factor is of secondary importance in the Pacific Coast States, where good coking coals are less numerous than in the Eastern States. It contains less than 35 percent volatile matter (moisture- and ash-free basis); consequently it does not qualify as a gas coal. Coals 66 and 67 contain relatively low percentages of ash, moisture, and sulfur, and their volatile-matter content exceeds 35 percent; therefore, both qualify either as gas or coking coals. Coal 68 (Oklahoma) contains 6.8 percent moisture and 2.1 percent sulfur, and these are high for coking coals; it is a high-volatile B coal and ordinarily would not be considered a coking coal. The high content of sulfur in coal 68 detracts from its value as a gas coal. Coals 69 and 70 (Arkansas) are low-volatile coals used for blending, for which purpose they are satisfactory because they have high agglutinating values and contain relatively low percentages of moisture, ash, and sulfur.

Table 9 gives the yields of carbonization products at 900° C. from coals 64 to 67, inclusive, for blending coals 28, 56, and 57, and also for the blends. The yields varied in a normal manner with the rank of coal. Low-volatile coals 56 and 57 gave high yields of coke and low yields of tar, light oil, and ammonium sulfate. High-volatile coals 28, 65, 66, and 67 gave low yields of coke and high yields of tar, light oil, and ammonium sulfate. As expected from its intermediate rank, medium-volatile

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47/ Fieldner, A. C., Davis, J. D., Reynolds, D. A., Brewer, R. E., Sprunk, G. C., and Schmidt, L. D., Carbonizing Properties and Petrographic Composition of Lower Banner-Bed Coal from Keen Mountain Mine, Buchanan County, Va., and the Effect of Blending this Coal with Pittsburgh-Bed (Warden Mine) Coal: Bureau of Mines Tech. Paper 616, 1940, 47 pp. Fieldner, A. C., Davis, J. D., Selvig, W. A., Reynolds, D. A., Brewer, R. E., Sprunk, G. C., and Holmes, C. R., Carbonizing Properties and Petrographic Composition of Upper Freeport Coal from Morgantown District, Monongalia County, W. Va., and of Lower Freeport Coal from Eastern Indiana County near Cambria County, Pa.: Bureau of Mines Tech. Paper 621, 1941, 77 pp.

48/ Fieldner, A. C., and Davis, J. D., Gas-, Coke-, and Byproduct-Making Properties of American Coals and Their Determination: Bureau of Mines Mon. 5, 1934, 164 pp.

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TABLE 8. - Analyses of coals, as carbonized[1/]

Coal 64 - Bakerstown bed, No. 23 mine, Tucker County, W. Va.
Coal 65 - Washington No. 2 bed, Bartoy mine, Pierce County, Washington.
Coal 66 - Miller bed, Wilkeson-Miller mine, Pierce County, Washington.
Coal 67 - Taggart bed, Lynch mine, Harlan County, Ky.
Coal 68 - Henryetta bed, Atlas No. 2 mine, Okmulgee County, Okla.
Coal 69 - Lower Hartshorne bed, Great Western mine, Sebastian County, Ark.
Coal 70 - Upper Hartshorne bed, Quality mine, Sebastian County, Ark.
Coal 56 - Pocahontas No. 3 bed, Buckeye No. 3 mine, Wyoming County, W. Va.
Coal 57 - Pocahontas No. 4 bed, No. 4 mine, Raleigh County, W. Va.
Coal 28 - Pittsburgh bed, Warden mine, Allegheny County, Pa.

Coal No.[2/]	Dry, mineral-matter-free, fixed carbon	Moist mineral-matter-free B.t.u.	Proximate, percent				Ultimate, percent					Heating value, B.t.u. per lb.
			Moisture	Volatile matter	Fixed carbon	Ash	Hydrogen	Carbon	Nitrogen	Oxygen	Sulfur	
64	77.1	15,450	2.2	21.6	70.5	5.7	4.8	82.1	1.6	4.8	1.0	14,470
64A	65.6	15,120	2.0	32.3	60.3	5.4	5.4	79.7	1.5	7.1	.9	14,210
64B	66.4	15,120	2.0	31.6	61.2	5.2	5.3	80.1	1.6	6.9	.9	14,240
65	68.4	15,180	2.2	28.1	58.3	11.4	5.2	74.0	2.3	6.5	.6	13,270
66	59.7	15,100	1.7	37.5	54.5	6.3	5.7	77.4	2.1	7.9	.6	14,040
67	63.7	15,070	2.5	33.8	58.3	5.4	5.4	79.1	1.4	7.9	.8	14,160
67A	66.9	15,020	2.3	30.9	61.3	5.5	5.2	79.7	1.4	7.5	.7	14,100
67B	68.4	15,150	2.2	29.5	62.6	5.7	5.2	80.4	1.4	6.6	.7	14,190
67C	67.0	15,080	2.0	30.8	61.3	5.9	5.2	79.5	1.4	7.3	.7	14,090
67D	69.2	15,060	2.3	28.8	63.1	5.8	5.1	79.7	1.4	7.2	.8	14,090
67E	75.7	15,290	1.7	23.0	69.4	5.9	4.7	81.6	1.4	5.5	.9	14,280
68	62.0	13,800	6.8	33.9	54.0	5.3	5.6	72.5	1.8	12.7	2.1	12,970
68A	66.3	14,130	5.6	30.4	58.4	5.6	5.3	75.0	1.8	10.5	1.8	13,230
68B	68.2	14,250	5.3	28.7	60.0	6.0	5.1	75.3	1.7	10.1	1.8	13,280
68C	66.2	14,140	5.7	30.5	58.4	5.4	5.4	75.0	1.8	10.7	1.7	13,280
68D	68.3	14,290	5.2	28.8	60.6	5.4	5.2	76.0	1.8	9.9	1.7	13,420
69	81.9	15,360	1.6	17.1	73.5	7.8	4.2	81.7	1.7	3.4	1.2	14,020
70	80.9	15,360	1.6	18.3	74.9	5.2	4.5	83.9	1.8	3.9	.7	14,470
56	81.7	15,520	1.6	17.4	74.5	6.5	4.4	83.7	1.2	3.6	.6	14,400
57	83.3	15,510	1.4	16.0	75.6	7.0	4.3	82.6	1.3	3.7	1.1	14,300
28	61.8	15,080	1.9	34.7	58.0	5.4	-	-	-	-	-	-

1/ Analyses by H. M. Cooper, chemist, Bureau of Mines.
2/ Coal 64A contains 80 percent and coal 64B contains 70 percent Pittsburgh-bed coal (No. 28); coal 67A contains 20 percent (No. 56) and 67B 30 percent Pocahontas No. 3 coal (No. 56); coal 67C contains 20 percent and coal 67D 30 percent Pocahontas No. 4 (No. 57); coal 68A contains 20 percent and 68B 30 percent Lower Hartshorne-bed coal (No. 69); coal 68C contains 20 percent and 68D 30 percent Upper Hartshorne-bed coal (No. 70); coal 67E contains 60 percen Pocahontas No. 4.

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Table 9 gives the yields of carbonization products at 900° C. from coals 64 to 67, inclusive, for blending coals 28, 56, and 57, and also for the blends. The yields varied in a normal manner with the rank of coal. Low-volatile coals 56 and 57 gave high yields of coke and low yields of tar, light oil, and ammonium sulfate. High-volatile coals 28, 65, 66, and 67 gave low yields of coke and high yields of tar, light oil, and ammonium sulfate. As expected from its intermediate rank, medium-volatile coal 64 gave yields of coke and byproducts intermediate between those from the high- and low-volatile coals. The yield of gas, upon the volume basis, did not vary with the rank of coal, but upon the basis of heat in gas per pound of coal carbonized the differences due to rank are apparent. The yield for coals 65 and 66 differs greatly, but this difference is expected because (although both are high-volatile A coals) coal 65 is very high in that rank, whereas coal 66 is correspondingly low. The yield from coals 28 and 67 checks very closely, except for light oil; both are representative high-volatile coals suitable for gas or coke-making. Blending the high-volatile coals with low-volatile coals increased the yield of coke and decreased the yield of byproducts; blending the medium-volatile coal with high-volatile coal decreased the yield of coke and increased the yield of byproducts.

Table 10 gives the results of physical tests of coke from coals 28, 56, 57, 65, 66, 67 and 68, and from blends of these coals, on carbonization in the 18-inch retort at 900° C. The strongest cokes, as measured by the shatter and tumbler tests, were obtained from coals 65, 56, and 57. As noted above, coal 65 is high in the high-volatile A rank of coals and therefore, as expected, yielded stronger cokes than were obtained from coals more representative of that rank, such as coal 67. The coke from coal 66 is weaker than the average for high-volatile A coking coals; it is of about the same strength as that from high-volatile B coal 68. Blending coal 67 with low-volatile coals 56 and 57 in proportions of 20 and 30 percent improved the strength of coke, and coal 57 was slightly better than coal 56 for this purpose. Blending with low-volatile coals 69 and 70 improved the physical properties of the coke from coal 68 considerably. The cokes from the blends of coal 68 are about as strong as those from the blends of coal 67, although coal 67 yielded stronger coke than coal 68 when each was carbonized singly. These results indicate: (1) Coke of good physical properties may be obtained from high-volatile B coal if suitably blended; and (2) low-volatile coals 69 and 70 (Arkansas) have satisfactory blending properties.

Three blends of Alabama coals, previously carbonized in Koppers by-product ovens, were carbonized in the BM-AGA 13-inch retort at 800° C. and also in the vertical slot oven. The heating program was designed to approach that of commercial ovens. Physical tests of the cokes indicated that the test cokes were stronger than those from the ovens. However, the BM-AGA test has the advantages that blends can be proportioned and mixed more accurately and that the charges are unaffected by weather. The results of the byproduct-oven and small-scale tests indicate that coke of foundry quality can be produced from these blends.

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TABLE 9. - Yields of carbonization products obtained at 900° C. in 18-inch retort

Coal 64 - Bakerstown bed, No. 23 mine, Tucker County, W. Va.
Coal 65 - Washington No. 2 bed, Bartoy mine, Pierce County, Wash.
Coal 66 - Miller bed, Wilkeson-Miller mine, Pierce County, Wash.
Coal 67 - Taggart bed, Lynch mine, Harlan County, Ky.
Coal 56 - Pocahontas No. 3 bed, Buckeye No. 3 mine, Wyoming County, W. Va.
Coal 57 - Pocahontas No. 4 bed, No. 4 mine, Raleigh County, W. Va.
Coal 28 - Pittsburgh bed, Warden mine, Allegheny County, Pa.

Coal No. 1/	Yields per ton of coal						B.t.u. in gas per pound of coal
	Coke, percent	Gas, cubic feet	Tar, gallons	Light oil in gas, gallons	$(NH_4)_2SO_4$, pounds	Liquor, percent	
64	78.6	10,500	7.6	1.76	21.9	4.6	3,100
64A	71.1	10,400	14.1	3.07	24.1	5.8	3,120
64B	72.0	10,550	13.1	2.85	24.3	5.6	2,990
65	73.7	10,200	10.6	2.65	34.0	4.9	3,060
66	66.0	11,200	15.2	3.96	32.5	5.1	3,570
67	68.6	10,550	14.4	3.86	20.5	6.6	3,250
67A	71.8	10,250	13.9	3.09	20.1	6.1	3,060
67B	73.3	10,200	12.6	2.73	19.0	5.9	2,990
67C	71.9	10,250	13.6	2.98	19.9	6.2	3,100
67E	78.4	10,300	6.9	1.91	18.7	4.8	2,850
28	68.8	10,650	14.9	2.79	19.0	6.4	3,230
56	84.0	10,450	4.1	1.36	13.4	2.7	2,610
57	84.3	10,250	3.2	1.29	14.5	2.4	2,590

1/ Coal 67A contains 20 percent and 67B 30 percent Pocahontas No. 3-bed coa (No. 56); coal 67C contains 20 percent and coal 67E 60 percent Pocahont No. 4-bed coal (No. 57); coal 64A contains 80 percent and coal 64B 70 percent Pittsburgh-bed coal (No. 28).

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TABLE 10. - Physical properties of cokes carbonized at 900° C. in 18-inch retort

Coal 65 - Washington No. 2 bed, Bartoy mine, Pierce County, Wash.
Coal 66 - Miller bed, Wilkeson-Miller mine, Pierce County, Wash.
Coal 67 - Taggart bed, Lynch mine, Harlan County, Ky.
Coal 68 - Henryetta bed, Atlas No. 2 mine, Okmulgee County, Okla.
Coal 56 - Pocahontas No. 3 bed, Buckeye No. 3 mine, Wyoming County, W. Va.
Coal 57 - Pocahontas No. 4 bed, No. 4 mine, Raleigh County, W. Va.

Coal No.1/	True specific gravity	Apparent specific gravity	Cells, percent	Shatter test, cumulative percent upon-				Tumbler test, cumulative percent upon-			
				2 in. screen	1-1/2 in. screen	1 in. screen	1/4 in. screen	2 in. screen	1-1/2 in. screen	1 in. screen	1/4 in. screen
65	1.93	.91	52.8	52.5	85.2	95.7	98.7	7.0	41.9	69.2	76.7
66	1.88	.83	55.9	17.7	40.3	79.6	98.1	.0	1.2	30.4	76.0
67	1.84	.82	55.4	48.4	75.9	90.1	97.8	.4	14.7	45.8	69.5
67A	1.84	.83	54.9	56.6	83.1	93.2	98.4	4.3	27.0	53.0	70.5
67B	1.84	.84	54.3	59.2	80.9	94.2	98.4	5.5	26.7	55.2	71.7
67C	1.82	.85	53.3	50.4	79.3	93.3	98.4	5.9	27.3	56.0	72.8
67E	1.86	.87	53.2	57.3	82.1	94.7	98.7	8.4	32.3	59.3	72.5
68	—	.78	—	18.3	46.6	82.3	97.9	.0	2.4	36.3	76.3
68A	—	.81	—	43.6	73.5	92.0	98.2	1.9	24.2	58.7	74.8
68B	—	.83	—	51.1	77.4	94.2	98.5	4.7	29.1	62.9	75.2
68C	—	.84	—	41.1	76.7	90.0	98.3	1.4	29.0	62.5	77.0
68D	—	.82	—	44.4	75.6	93.7	98.5	2.9	25.9	61.9	77.7
56	1.86	.90	51.6	59.9	83.3	94.6	98.5	5.2	32.5	59.3	71.5
57	1.88	.91	51.6	62.2	87.3	95.2	98.3	9.0	37.4	60.7	70.6

1/ Coal 67A contains 20 percent and coal 67B 30 percent Pocahontas No. 3-bed coal (No. 56); coal 67C contains 20 percent and coal 67E 60 percent Pocahontas No. 4-bed coal (No. 57); coal 68A contains 20 percent and coal 68B 30 percent Lower Hartshorne-bed coal (No. 69); coal 68C contains 20 percent and coal 68D 30 percent Upper Hartshorne-bed coal (No. 70).

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Preliminary to the testing of coal 68 (Oklahoma), small-scale carbonization tests were made of this coal singly and in blends with four low-volatile Arkansas coals. These tests were made at 900° C. in a retort of 4 pounds capacity, and the yields of coke, gas, tar and liquor were determined. The cokes were tested in a small-scale tumbler apparatus. The results of this survey indicated that the coke-making property of coal 68 is improved greatly by blending with low-volatile Arkansas coals. Two of the Arkansas coals (69 and 70) were selected for the blends to be carbonized in the BM-AGA tests, the results of which, discussed above, verified the conclusion reached from this preliminary survey.

An investigation of the carbonizing properties of four medium-volatile coals of similar chemical composition, but differing in type, showed that three bright coals (55, 60, and 64) expanded and yielded stronger coke than the splint coal (58), which contracted. The more significant chemical and petrographic data pertaining to these coals are given in table 11. The 1-1/2-inch shatter-test indexes were: 58, 82.6; 55, 85.7; 60, 88.9; and 64, 88.0. The 1-inch tumbler-test indexes were: 58, 65.4; 55, 68.9; 60, 69.8; and 64, 72.3. Coal 58 contracted 6.2 percent in the sole-heated oven, whereas the bright coals expanded 9.8 to 19.0 percent. The results of this study indicate that the high propertion of splint and cannel types in coal 58 modifies its plasticity during carbonization and thereby causes it to contract and yield weaker coke than is obtained from the three bright coals.

TABLE 11. - Chemical and petrographic composition of 4 medium-volatile coals.

Coal No.	Bed	Dry, mineral-matter-free, fixed carbon, percent	Proximate analyses, percent,				Petrographic analyses, types, percent			
			Moisture	Volatile matter	Fixed carbon	Ash	Bright	Semi-splint	Splint	Cannel
58	Lower Banner	76.9	2.5	21.4	67.8	8.3	36	53	-	11
55	Sewell	77.5	1.6	21.8	73.7	2.9	81	15	4	-
60	Lower Freeport	73.4	2.0	24.9	66.7	6.4	93	5	2	-
64	Bakerstown	77.1	2.2	21.6	70.5	5.7	91	1	6	-

Plasticity. - The plastic properties of all coals and blends studied in the survey of carbonizing properties of American coals during the year were determined by the Agde-Damm dilatometer and by the Davis and Gieseler

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plastometer test methods.[49] Tests were made also by one or more of these methods on a series of special coals and blends. The plastic properties of coals 56, 57, and 28 (table 8) used for blending have been published.[50]

Medium-volatile Bakerstown coal 64 (table 8) showed a plastic temperature range of 100° C. This is abnormally long for coals of this rank and may be a factor in the formation of spongy coke from this coal. Blends 64A and 64B showed plastic properties characteristic for blends of high-volatile A rank. Coals 65 and 66 contain 68.4 and 59.7 percent, respectively, of dry, mineral-matter-free fixed carbon. They thus represent almost the extreme upper and lower limits of coals of high-volatile A rank. Their plastic properties, determined by all three methods of test, showed characteristics normal for coals of these relative ranks. High-volatile A Taggart-bed coal 67 gave plastic properties representative of a coal of average high-volatile A rank. This coal was characterized by high fluidity, as determined by the Gieseler test. Blends 67A, 67B, and 67C contain enough of the low-volatile Pocahontas coals to increase their ranks appreciably above that of coal 67. This increase in rank is reflected in higher characteristic temperature of plasticity, higher maximum resistance, and lower fluidity compared to those of coal 67. Blends 67D and 67E contain enough of the low-volatile Pocahontas No. 4 bed coal to make them of medium-volatile rank. These blends showed normal plastic properties for coal blends of this rank. The high-volatile B coal 68 gave only a slight fusion in the Davis plastometer test and a low degree of fluidity in the Gieseler plastometer test. Such results would be expected for a coal of this low bituminous rank. Blends 68A, 68B, 68C, and 68D of high-volatile B coal 68 and the designated amounts of low-volatile coals 69 and 70 have the dry, mineral-matter-free fixed-carbon content representative of high-volatile A coals. However, the first three of these blends showed no fusion in the Davis plastometer tests. The lack of fusion might be expected because constituent coals 68 and 69 showed no fusion by this test, and coal 70, of slightly lower rank than coal 69, immediately gave a high maximum resistance and a very short (about 69°C.) plastic temperature range. There was just enough fluid material in coal 70 to form a hard coke. The more sensitive Gieseler test showed that coal 70 was more fluid than coal 69.

Three coals of high rank (fixed carbon, more than 81.9) showed no fusion in the Davis plastometer tests, which agrees with previous experience. If tested at a higher rate of heating, such coals can be made to

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[49] Brewer, R. E., and Atkinson, R. G., Plasticity of Coals - Its Measurement and Relation to Quality of Coke Produced: Ind. Eng. Chem., anal. ed., vol. 8, 1936, pp. 443-449.
Brewer, R. E., and Triff, J. E., Measurement of Plastic Properties of Bituminous Coals. Comparison of Gieseler and Davis Plastometer and Agde-Damm Dilatometer Methods: Ind. Eng. Chem., anal. ed., vol. 11, 1939, pp. 242-249.

[50] Fieldner, A. C., Davis., J. D., Reynolds, D. A., Schmidt, L. D., Brewer, R. E., Sprunk, G. C., and Holmes, C. R., Carbonizing Properties and Petrographic Composition of Pocahontas No. 3-Bed Coal from Buckeye No. 3 Mine, Wyoming County, W. Va., and of Pocahontas No. 4-Bed Coal from No. 4 Mine, Raleigh County, W. Va.: Bureau of Mines Tech. Paper 604, 1940, 65 pp.

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fuse. The Giesler plastometer tests showed that the fluidity of these low-volatile coals decreased with increasing rank of the coals.

The Taggart-bed coal increased somewhat in rank with oxidation at 100° C. in the accelerated weathering tests up to 15.5 days and then decreased. The characteristic temperatures of plasticity were raised, the maximum resistance increased, and the fluidities decreased until after oxidation for 15.5 days, when the samples no longer showed fusion in the Davis plastometer test.

Accelerated Weathering Tests and Storing Qualities of Coking Coals. - Samples representative of 12 different coal beds have been oxidized progressively in 400-pound lots in air at 99.3°C. These coals showed a wide range in characteristic rate of oxidation. The characteristic rate of oxidation is high for coals of high original oxygen content and for coals with a high content of volatile matter.[51] However, studies of oxidation rates showed that small changes in the conditions of storage affect the rate of oxidation of coal so greatly that the differences in characteristic rates of various coals become relatively less important. For example, increasing the temperature of coal only 24° F. triples the rate of oxidation.[52]

Preoxidized samples (180 pounds) were carbonized at 800° C., and the yields and the physical properties of the resultant cokes[53] were measured by standard methods. In figure 15 the strength of coke from each coal tested is plotted against the amount of oxygen that has been consumed by the coal (moisture- and ash-free basis).

The coke-strength index is the weighted average[54] of the 1-1/2-inch shatter index, the percentage of the coal charge that fused and three tumbler indexes. The strength of coke from most coals remained fairly constant in the early stages of oxidation and then fell rapidly with further oxidation of the coal. The more fluid coals showed an appreciable increase in strength of coke in the early stages of oxidation. The coking power of all coals was destroyed by prolonged oxidation.

When the average coal had consumed 1.9 pounds of oxygen per 100 pounds of moisture- and ash-free coal (10 days oxidation in air at 99.3° C.) the coke-strength index showed a 15-percent decrease from the value for fresh coal, while the shatter index (1-1/2-inch) decreased only 6 percent, the

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51/ Schmidt, L. D., and Elder, J. L., Atmospheric Oxidation of Coal at Moderate Temperatures - Rates of the Oxidation Reaction for Representative Coking Coals: Ind. Eng. Chem., vol. 32, 1940, pp. 249-256.

52/ Schmidt, L. D., Effects of Storage and Oxidation of Coal Upon Coking Properties: Iron and Steel Eng., vol. 18, No. 3, March 1941, pp. 64-72.

53/ Schmidt, L. D., Elder, J. L., and Davis, J. D., Atmospheric Oxidation of Coal at Moderate Temperatures - Effect of Oxidation on the Carbonizing Properties of Representative Coking Coals: Ind. Eng. Chem., vol. 32, 1940, pp. 548-555.

54/ See work cited in footnote 52.

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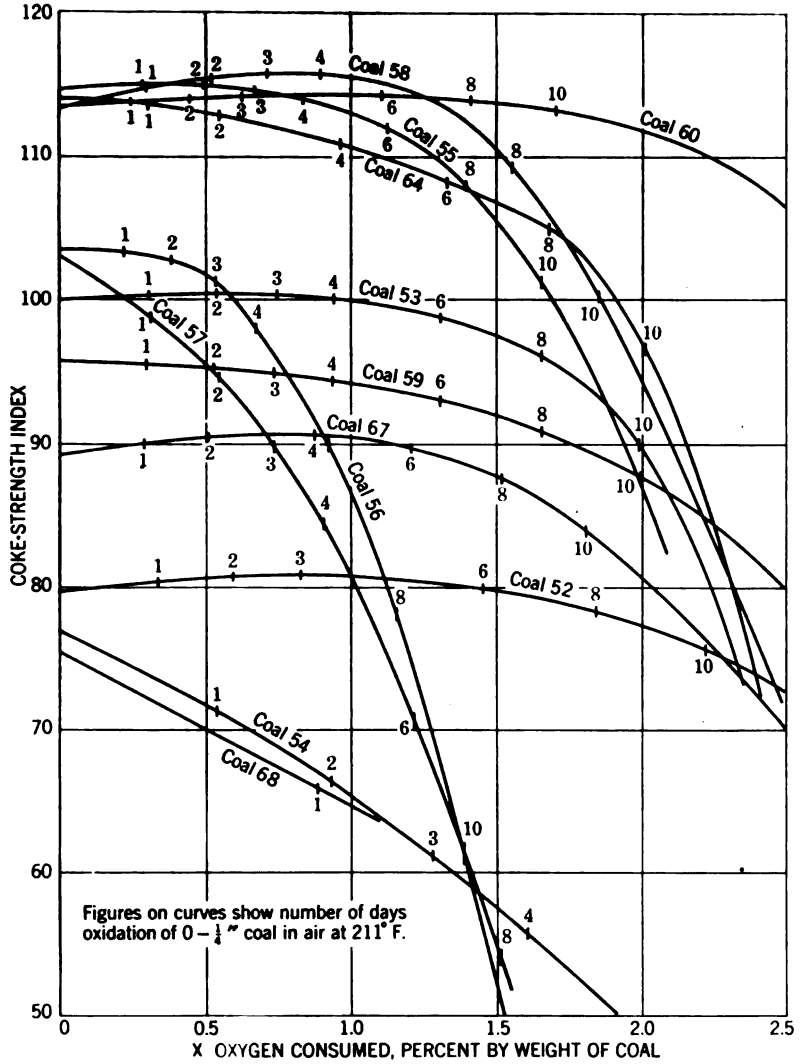

Figure 15.- Effect of oxidation of coal on the coke-strength index.

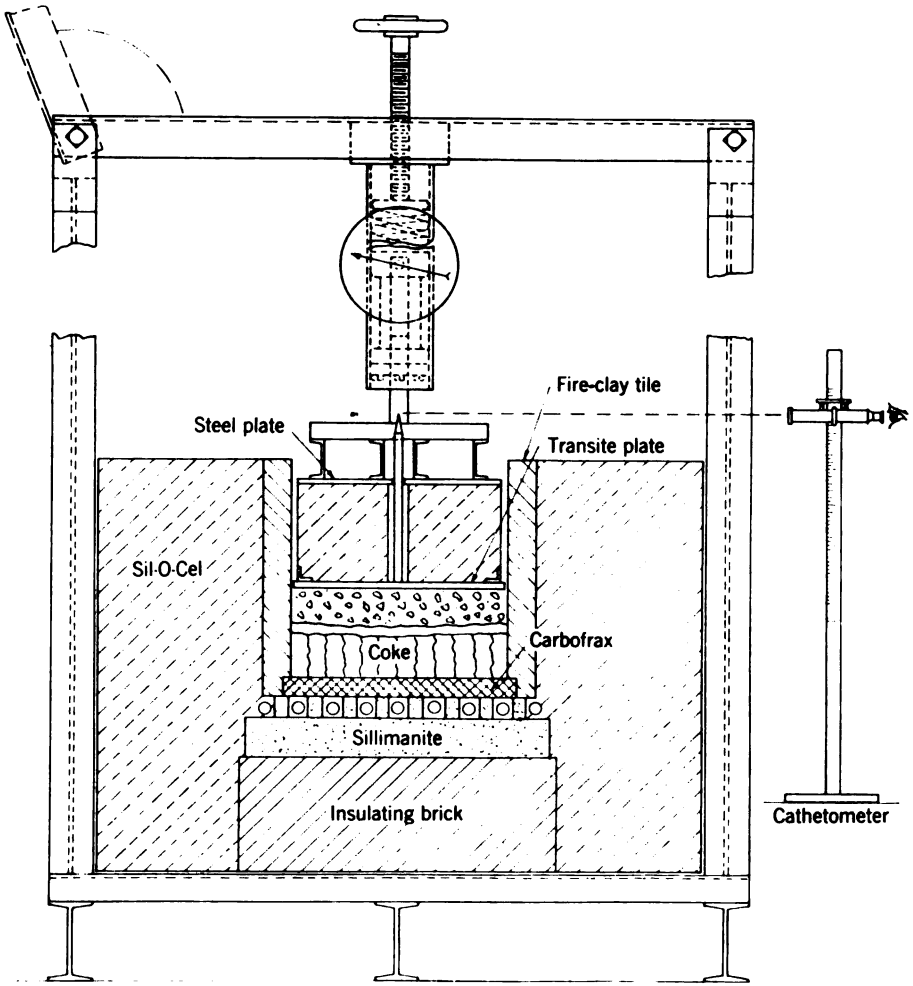

Figure 16.- Sole-heated oven.

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tumbler hardness decreased 17 percent, and 16 percent of the carbonized charge remained unfused, that is, passed a 1-inch screen.

The agglutinating value proved to be a satisfactory laboratory test for indicating the extent of oxidation of coal. Table 12 shows the change in agglutinating value with extent of oxidation. On the average, a 34-percent decrease in agglutinating value corresponds to a 15-percent decrease in coke-strength index. In this table, the coals are listed in the order of decreasing coke-strength indexes (fresh coal). The results show that strongly coking coals can be stored until the agglutinating value has decreased by a somewhat greater percentage than is the case for weakly coking coals.

TABLE 12. - Effect of oxidation on agglutinating value

Coal No.	Volatile matter, percent[1]	Agglutinating value								
		X^2[2] = 0, kg.	X^2[2] = 1		X^2[2] = 2		X^2[2] = 3		When strength index is lowered 15 percent	
			Kg.	Ratio[3]	Kg.	Ratio[3]	Kg.	Ratio[3]	Kg.	Ratio[3]
55	22.5	6.8	5.4	0.79	2.8	0.41	-	-	3.5	0.51
64	22.8	7.5	7.5	1	4.0	.53	2.0	.27	4.2	.56
60	26.6	7.0	7.1	1.01	6.3	.90	5.1	.73	5.0	.71
58	23.1	5.3	4.4	.83	3.5	.66	-	-	3.6	.68
56	18.3	5.1	4.0	.78	-	-	-	-	4.1	.80
57	16.7	6.8	3.6	.53	-	-	-	-	4.2	.62
53	33.9	8.2	7.4	.90	5.5	.67	-	-	5.2	.63
59	32.3	7.9	7.7	.97	5.4	.68	3.7	.47	4.6	.58
67	36.3	5.6	5.4	.96	3.8	.67	2.4	.42	3.5	.62
52	40.1	8.4	7.8	.93	6.8	.81	5.3	.63	5.6	.67
54	40.1	2.7	1.8	.67	1.6	.59	-	-	1.8	.67
68	38.0	4.5	4.1	.90	2.2	.49	-	-	4.0	.88
Ave.	29.2	6.32	5.52	.86	-	.64	-	.50	4.11	.66

1/ Moisture- and mineral-matter-free basis.
2/ X = oxygen consumed, percent by weight of moisture- and mineral-matter-free coal.
3/ Ratio of value for oxidized coal to corresponding value for fresh coal.

Determination of Swelling Properties of Coal During Coking Process. - Routine tests were made on coals received in connection with the survey (BM-AGA) of carbonizing properties of American coals, but the more important part of the year's work on this problem was an intensive study of the expanding properties of "borderline coals" or blends. By borderline coals is meant those likely to exert enough pressure on coke-oven walls to damage them under certain operating conditions and not under others. Coke-oven operating conditions were known for most of the blends; it was also known whether or not trouble from excessive expansion pressures had been experienced. The supply of such coals is limited, and they are in demand for making coke of high quality. Therefore, it is important to know their expanding properties to safeguard the oven walls; moreover, new combinations

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of coals should be tried as possible substitutes for the purpose of increasing the available supply of usable coals. Furthermore, it is easy to distinguish strongly expanding or strongly contracting coals, and the former in general will not be charged in byproduct coke ovens without blending with enough contracting coal to insure against trouble.

Usually laboratory tests of expanding (or contracting) properties of coal have involved heating from one side of the test chamber only, the load on the charge being maintained constant at about 2.2 pounds per square inch. It is realized that these carbonizing conditions do not simulate the conditions in a coke oven where heating is from both walls and where the volume of the space occupied by the charge does not change unless the pressure on the walls becomes high enough to deform them. It has not been shown experimentally that the two methods of test can be correlated satisfactorily; and the Bureau of Mines, among others, has felt that it is safest for the present to simulate in tests as closely as possible the carbonization conditions of the coke oven, that is, heating from both sides at constant volume and measuring the pressure developed. However, the constant-pressure tests with one-sided heating are being continued with the hope that ultimately the results can be correlated with the more expensive method involving two-sided heating.

The sole-heated oven (fig. 16) designed originally for testing a charge of approximately 40 pounds at constant pressure with heating from one side (the sole or floor) has been modified to permit testing at constant volume.

The vertical-slot oven (figs. 17 and 18) was designed originally for electrical heating from one side only and at constant pressure. It has been modified, however, to permit heating from both walls at constant volume. Moreover, a device has been provided for automatic program control of the temperature at both walls: this device consists of a commercial two-point recording potentiometer controller provided with replaceable time-temperature program control curves, as shown at the top of the instrument in figure 19. It controls automatically the temperature rise at both walls of the oven, which are heated electrically. The curves were calculated from data on coke-oven-wall heating programs available in the literature, and it is realized that they may be somewhat in error; however, it is true that there is a drop in coke-oven-wall temperatures at the time of charging which a constant temperature of the test-oven wall would not simulate. The pressure is adjusted periodically by means of the strain screw to keep the volume constant as indicated by readings on the distance gage (graduations, 0.01 inch), using the cathetometer shown. The pressures necessary to maintain this condition are read periodically and plotted against the carbonizing time. Thin steel retorts 27 inches wide by 44 inches high and of thickness up to 13 inches are used to hold the charges.

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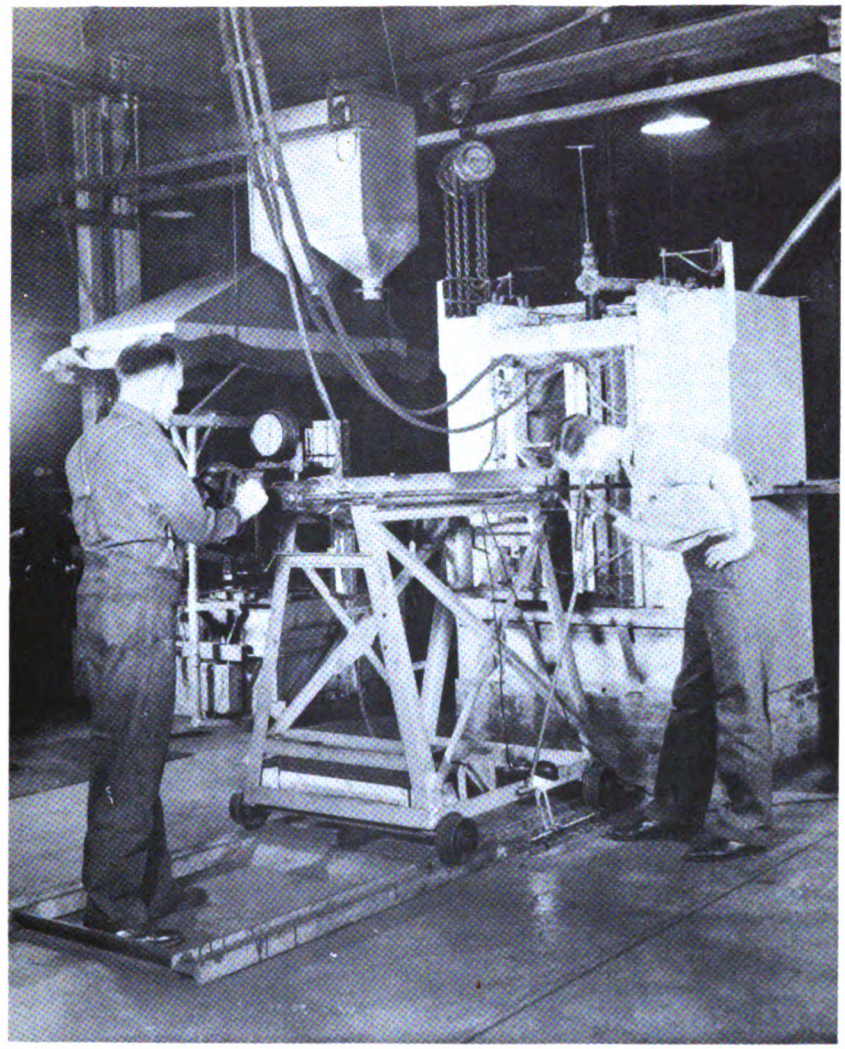

Figure 17.- Vertical-slot oven showing test in progress.

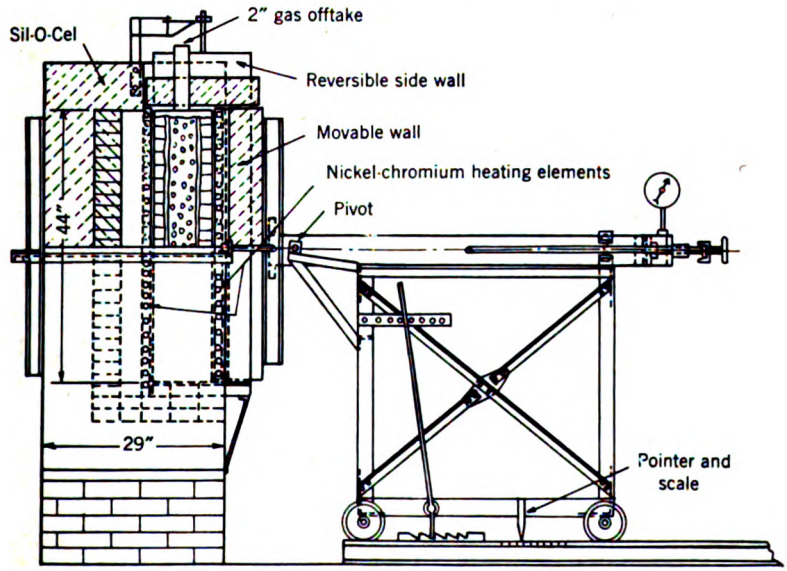

Figure 18.- Vertical-slot oven.

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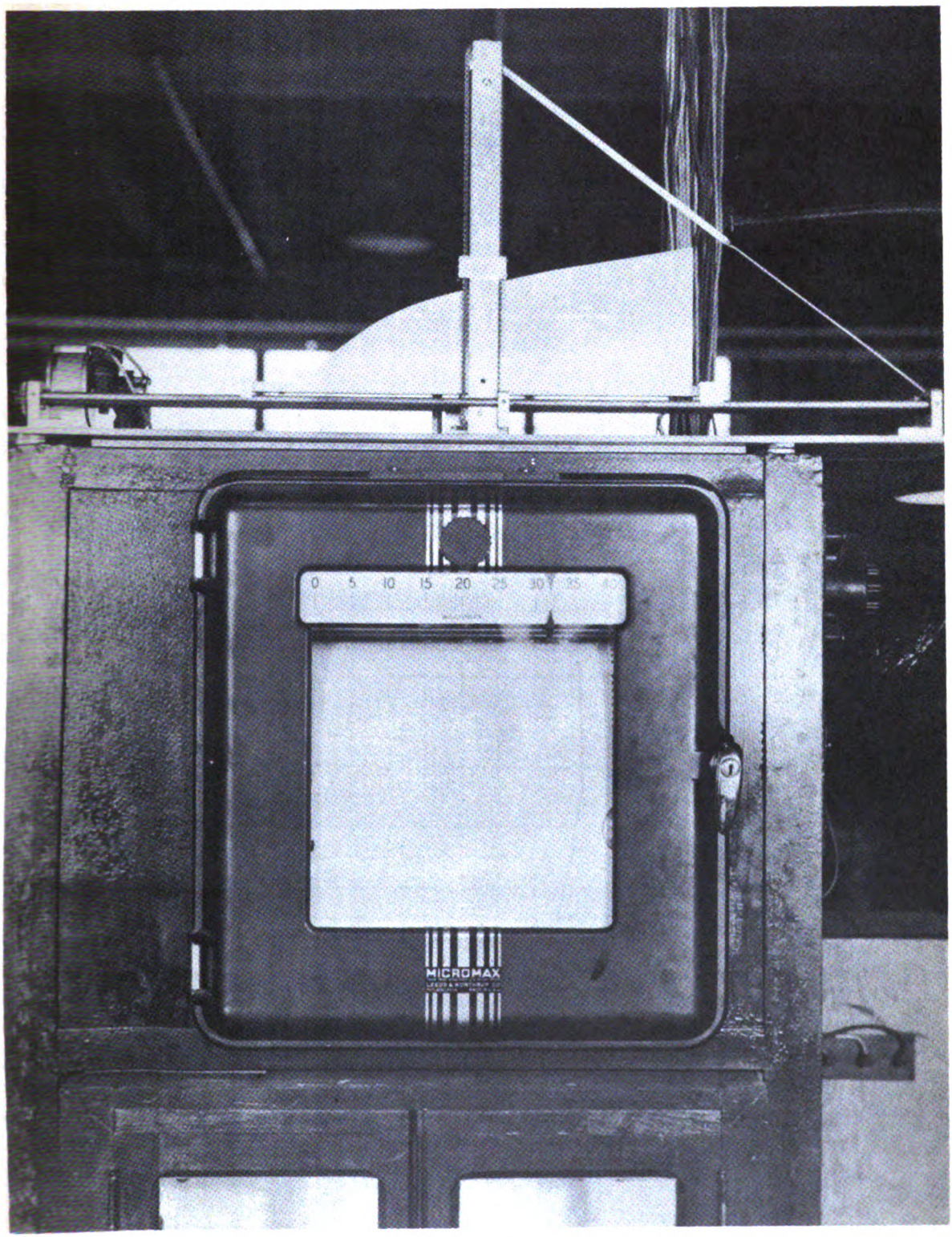

Figure 19.- Automatic heating program controller.

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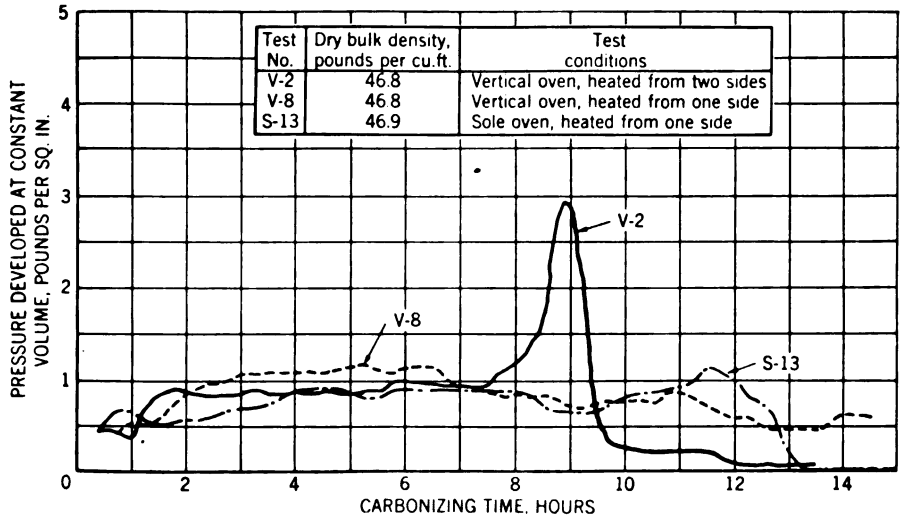
Test No. | Dry bulk density, pounds per cu.ft. | Test conditions
V-2 | 46.8 | Vertical oven, heated from two sides
V-8 | 46.8 | Vertical oven, heated from one side
S-13 | 46.9 | Sole oven, heated from one side
V-2
V-8
S-13
PRESSURE DEVELOPED AT CONSTANT VOLUME, POUNDS PER SQ. IN.
CARBONIZING TIME, HOURS

Figure 20.- Coking pressures, heating from one and two sides, foundry blend, coal XPm 26, vertical-slot and sole-heated ovens.

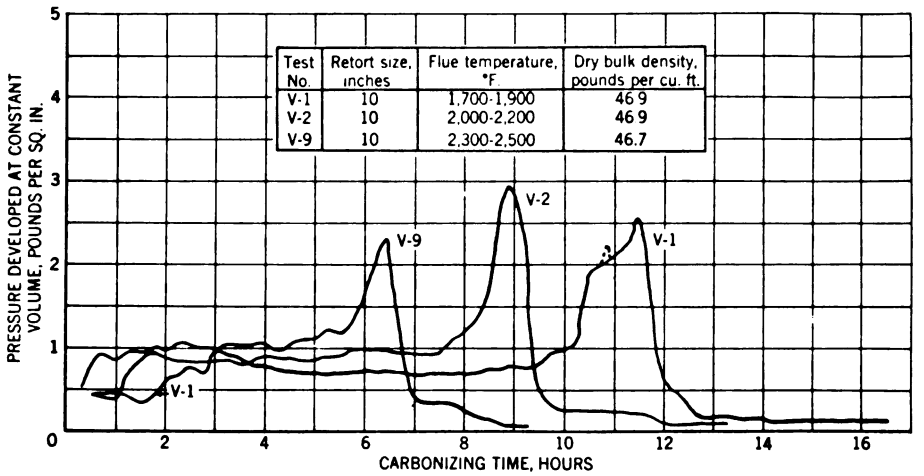
Test No. | Retort size, inches | Flue temperature, °F. | Dry bulk density, pounds per cu. ft.
V-1 | 10 | 1,700-1,900 | 46.9
V-2 | 10 | 2,000-2,200 | 46.9
V-9 | 10 | 2,300-2,500 | 46.7
V-2
V-9
V-1
V-1
PRESSURE DEVELOPED AT CONSTANT VOLUME, POUNDS PER SQ. IN.
CARBONIZING TIME, HOURS

Figure 21.- Effect of heating rate in vertical-slot oven, foundry blend, coal XPm 26.

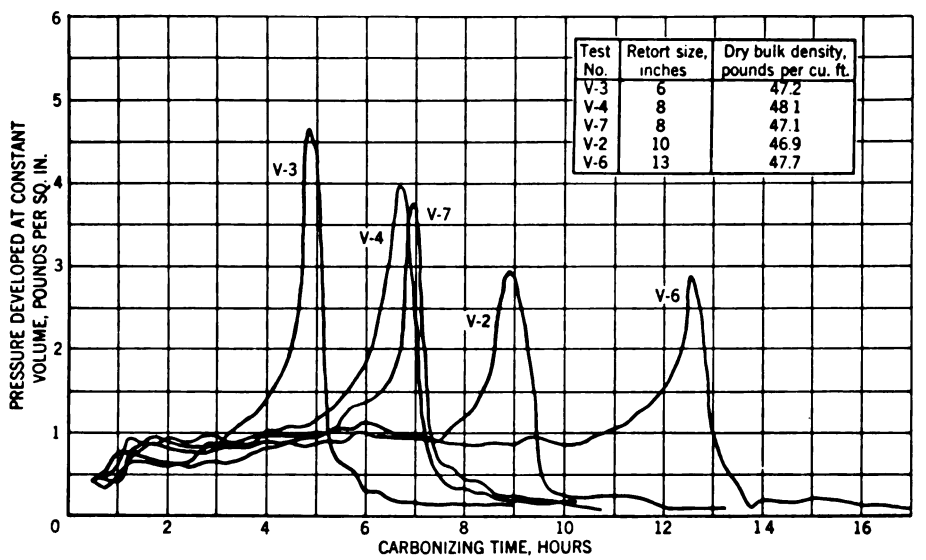
Test No. | Retort size, inches | Dry bulk density, pounds per cu. ft.
V-3 | 6 | 47.2
V-4 | 8 | 48.1
V-7 | 8 | 47.1
V-2 | 10 | 46.9
V-6 | 13 | 47.7
V-3
V-4
V-7
V-2
V-6
PRESSURE DEVELOPED AT CONSTANT VOLUME, POUNDS PER SQ. IN.
CARBONIZING TIME, HOURS

Figure 22.- Variation of peak pressures with width of vertical-slot oven, heated from both sides, foundry blend, coal XPm 26.

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Table 13 gives the origin and analyses of coals and blends tested, table 14 their expanding properties under the several conditions of test, and table 15 the physical properties of the cokes. The XP blends and the A13 series probably should be classed as borderline coals, coal 59 undoubtedly is dangerous, and the rest should be looked upon as safe, except perhaps under extreme coking conditions. More experimental work was done on blend XPm26, because it was known to give trouble when too dry in a 17-inch commercial oven operated with low flue temperatures. It must be realized that many borderline coals can be rendered safe in a given oven by proper adjustment of the operating conditions.

The results of tests on coal blend XPm26 follow. It was selected because of the greater certainty of its being a borderline coal.

Figure 20 shows the results of constant-volume tests with heating from one side in the sole-heated oven and with heating from one and both sides in the vertical-slot oven. The thickness of the charges for one-sided heating was 5 inches and that for two-sided heating 10 inches and the bulk density was kept the same for all tests as nearly as possible. Also, the same wall-temperature programs were maintained for all tests. Heating from both sides under these conditions gives a peak pressure about three times the maximum obtained in heating from one side only. The reason is the doubling of the two plastic layers near the end of the coking period. After the peak is reached, the pressure drops to nearly zero so that the charge might exert dangerous pressures on the oven walls and yet push satisfactorily from the oven. The curves for one-sided heating are in close agreement over virtually all of the heating period, but neither shows a pronounced peak pressure.

Figure 21 shows the effect of slow, medium, and rapid heating rates (heating programs) on peak pressures obtained, other carbonizing conditions being held constant as nearly as possible. The intermediate rate of heating gives slightly the highest peak pressure, but one of the coals of the blend (Pittsburgh bed) is believed to have a negative temperature-expansion coefficient, which may account for the results obtained. However, the variation in maximum pressure with rate of heating probably should be considered small.

Figure 22 shows the effect on peak pressures developed in the vertical-slot oven with charges of different thickness, other carbonizing conditions being held constant. The intermediate carbonization temperature program was used for all tests. The peak pressures decrease fairly uniformly as the thickness of the charge is increased from 6 to 10 inches; the pressures for 10- and 13-inch charges are approximately the same. Probably the main reason for the high peaks found for the very thin charges is that less coke has been formed up to this point, and therefore the relief of the pressure by shrinkage of the coke[55] is less than with the thicker charges. If this is the true explanation, one must assume that with the thicker charges the plastic pressure must be more nearly balanced by shrinkage of the coke.

55/ Auvil, H. S., Davis, J. D., and McCartney, J. T., Shrinkage of Coke: Bureau of Mines Rept. of Investigations 3539, 1940, 17 pp.

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TABLE 13. - Analyses of coals

Coal 57 - Pocahontas No. 4 (W. Va.)
Coal 56 - Pocahontas No. 3 (W. Va.)
Coal XP-20 - 53 percent Pocahontas No. 3 (W. Va.), 27 percent Bull Creek (Va.), and 20 percent Eagle (W. Va.).
Coal 55 - Sewell (W. Va.)
Coal 64 - Bakerstown (W. Va.)
Coal 58 - Lower Banner (Va.)
Coal 60 - Lower Freeport (Pa.)
Coal al3C - 40 percent Black Creek (Ala.), 40 percent Blue Creek (Ala.), 10 percent Pocahontas No. 1 (W. Va.), and 10 percent flotation fines from Black Creek coal
Coal al3A - 30 percent Black Creek (Ala.), 30 percent Blue Creek (Ala.), 30 percent Mary Lee (Ala.), and 10 percent Pocahontas No. 1 (W. Va.)
Coal XP-26 - 50 percent Beckley (W. Va.) and 50 percent Pittsburgh (W. Va.)
Coal XP-18 - Sewell (W. Va.)
Coal al3B - 35 percent Black Creek (Ala.), 40 percent Blue Creek (Ala.), and 25 percent Mary Lee (Ala.)
Coal al3D - 30 percent Black Creek (Ala.), 30 percent Blue Creek (Ala.), 30 percent Mary Lee (Ala.), and 10 percent flotation fines from Black Creek coal
Coal al3E - 45 percent Black Creek (containing approximately 16 percent flotation fines), 45 percent Mary Lee (Ala.), and 10 percent Pocahontas No. 1
Coal 59 - Upper Freeport (W. Va.)
Coal a59 - Upper Freeport (W. Va.)
Coal 53 - Pond Creek (W. Va.)
Coal 68 - Henryetta (Okla.)
Coal 63 - Lower Hignite (Ky.)

Coal	Dry, mineral-matter-free, fixed carbon	Proximate analysis, percent			
		Moisture	Volatile matter	Fixed carbon	Ash
57	82.0	1.5	17.1	74.1	7.3
56	81.6	1.3	17.5	74.7	6.5
XP-20	77.7	3.0	20.9	70.7	5.4
55	77.5	1.6	21.8	73.7	2.9
64	77.2	2.8	21.4	70.2	5.6
58	76.5	1.3	22.0	68.7	8.0
60	73.7	1.8	24.7	67.2	6.3
al3C	71.2	1.3	27.4	66.3	5.0
al3A	70.9	2.2	27.2	64.7	5.9
XP-26	70.7	1.8	27.5	64.7	6.0
XP-18	70.4	1.6	27.9	64.7	5.8
al3B	69.7	2.0	28.4	63.9	5.7
al3D	69.4	2.4	28.5	63.2	5.9
al3E	69.1	3.9	28.2	61.5	6.4
59	67.8	2.6	29.3	59.7	8.4
a59	67.7	2.4	30.0	61.4	6.2
53	66.1	2.7	31.9	61.1	4.3
68	62.0	6.8	33.9	54.0	5.3
63	59.9	2.1	37.4	55.0	5.5

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TABLE 14. - Pressures developed in vertical slot oven at constant volume. Effect of retort thickness and heating rate. Comparison with expansion in sole-heated oven at constant pressure.

Coal	Test No.	Vertical oven: Retort size, inches	Equivalent flue temp., °F.	Moisture, percent	Bulk density, pounds per cubic foot: As tested	Bulk density, pounds per cubic foot: Dry	Maximum pressure, lbs. per sq. in.	Sole-heated oven: Expansion (or contraction) At bulk density of vertical test	Sole-heated oven: Expansion (or contraction) At 55.5 lbs. per cu. ft.
XPm20	V-1	10	1700-1900	4.6	50.0	47.7	3.8	-4.2[1]	+6.4[1]
58	V-3	6	2000-2200	1.3	51.6	50.9	2.0		
58	V-1	10	do	1.3	53.3	52.6	2.3	-9.1[1]	-5.3[1]
58	V-2	13	do	1.3	54.9	54.2	3.5		
al3C	V-3	10	1700-1900	1.3	52.2	51.5	2.0	-6.9[1]	-1.0[1]
al3A	V-1	10	do	2.2	51.6	50.5	4.3	-6.0	+1.2
al3B	V-2	10	do	2.0	50.7	49.7	4.2	-9.2	- .6
al3D	V-4	10	do	2.4	53.9	52.6	4.5[2]		
al3E	V-5	10	do	3.9	50.2	48.2	.7		
XPm26	V-1	10	1700-1900	5.0	49.4	46.9	2.6		
XPm26	V-2	10	2000-2200	4.6	49.2	46.9	2.9	-9.6[1]	+2.1[1]
XPm26	V-5	10	2300-2500	4.2	49.4	47.3	1.6		
XPm26	V-9	10	do	5.0	49.2	46.7	2.3		
XPm26	V-3	6	2000-2200	5.0	49.7	47.2	4.7		
XPm26	V-4	8	do	4.1	50.2	48.1	4.0		
XPm26	V-7	8	do	4.3	49.2	47.1	3.7		
XPm26	V-2	10	do	4.6	49.1	46.8	2.9		
XPm26	V-6	13	do	4.9	49.8	47.4	2.9		
XPm26	V-8	5	2000-2200[3]	6.0	49.8	46.8	1.2[4]		
XPmb18	V-2	10	2000-2200[5]	3.3	49.8	48.2	2.2	-10.3[1]	0.0[1]
a59	V-2	6	1700-1900	2.4	49.1	47.9	4.4[6]		
a59	V-1	10	do	2.4	50.4	49.2	4.3[7]	+0.2	+10.3
68	V-1	10	2000-2200	6.8	49.9	46.5	.9	-13.0	-3.3
63	V-1	10	2300-2500	2.1	50.0	49.0	.5[4]	-14.6	-5.2

[1] These results are theoretically adjusted for varying moisture contents in sole- and vertical-oven charges.
[2] Retort expanded 1.5 percent under this limited applied pressure.
[3] Heated from 1 side only.
[4] These tests did not show a peak pressure.
[5] Temperatures were somewhat lower than the standard 2,000°-2,200° F. curve.
[6] Retort expanded 4.6 percent under this limited applied pressure.
[7] Retort expanded 0.5 percent under this limited applied pressure.

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TABLE 15. - Physical properties of cokes made in vertical-slot expansion oven. Effect of heating rate and thickness of retort. Comparison with cokes made in BM-AGA cylindrical retort

Coal	Oven	Retort size, inches	Heating schedule	Shatter test, cumulative percent upon-				Tumbler test, cumulative percent upon-				Apparent specific gravity
				2-in. screen	1-1/2-in. screen	1-in. screen	1/4-in. screen	2-in. screen	1-1/2-in. screen	1-in. screen	1/4-in. screen	
XPm20	Expansion	10	1700°-1900°F.	95.6	96.6	98.0	98.9	38.6	61.5	65.6	67.3	0.91
58	do	6	2000°-2200°F.	94.8	97.0	97.8	99.0	46.5	65.0	70.7	74.8	.98
58	do	10	do	92.7	96.6	97.9	99.1	47.1	69.8	75.8	78.0	1.02
58	do	13	do	90.0	96.1	97.9	99.0	43.6	69.0	75.1	77.0	1.04
58	BM-AGA	18	800°C.	88.2	94.8	97.2	98.7	38.9	66.6	71.4	73.5	.95
al3C	Expansion	10	1700°-1900°F.	93.7	97.4	98.0	99.0	46.8	69.5	73.4	74.3	.92
al3C	BM-AGA	18	800°C.	78.0	93.8	97.5	98.8	23.8	63.1	75.1	77.2	.90
al3A	Expansion	10	1700°-1900°F.	93.2	96.6	97.4	98.5	42.6	69.5	72.3	73.6	.93
al3A	BM-AGA	18	800°C.	89.5	95.7	97.6	98.5	39.6	66.7	72.2	74.1	.87
XPm26	Expansion	10	1700°-1900°F.	94.5	97.2	98.2	99.0	43.8	66.9	70.9	72.4	.86
XPm26	do	10	2000°-2200°F.	93.0	96.7	98.2	99.1	35.7	63.7	71.8	74.6	.85
XPm26	do	10	2300°-2500°F.	79.3	91.5	97.3	99.0	26.5	56.8	69.8	75.5	.86
XPm26	do	6	2000°-2200°F.	89.6	96.3	97.8	99.0	39.7	63.1	70.0	73.5	.87
XPm26	do	8	do	89.4	96.0	98.0	99.0	39.5	67.5	72.2	73.9	.88
XPm26	do	10	do	93.0	96.7	98.2	99.1	35.7	63.7	71.8	74.6	.85
XPm26	do	13	do	90.8	96.3	98.2	99.1	42.6	68.3	72.6	74.5	.87
XPmb18	do	10	1/ 2000°-2200°F.	84.7	95.8	97.7	99.0	31.5	63.8	71.1	73.7	.91
al3B	do	10	1700°-1900°F.	91.5	95.6	97.6	98.7	44.5	68.8	72.6	74.9	.93
al3B	BM-AGA	18	800°C.	87.1	95.4	97.5	98.5	31.6	64.2	73.0	75.4	.87
al3D	Expansion	10	1700°-1900°F.	94.7	96.9	98.0	99.0	41.8	68.8	74.3	76.0	.93

See footnote on page 47.

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TABLE 15. - Physical properties of cokes made in vertical-slot expansion oven. Effect of heating rate and thickness of retort. Comparison with cokes made in BM-AGA cylindrical retort. Cont'd.

Coal	Oven	Retort size, inches	Heating schedule	Shatter test, cumulative percent upon-				Tumbler test, cumulative percent upon-				Apparent specific gravity
				2-in. screen	1-1/2-in. screen	1-in. screen	1/4-in. screen	2-in. screen	1-1/2-in. screen	1-in. screen	1/4-in. screen	
a13E	do	10	do	93.4	96.8	97.7	98.8	43.7	63.4	67.9	69.8	.92
a59	do	6	do	90.7	94.5	97.1	98.6	29.4	55.1	63.7	70.9	.89
a59	do	10	do	78.4	88.7	95.3	98.5	20.3	39.2	57.7	74.4	.92
59	BM-AGA	18	800°C.	75.0	87.5	93.9	98.4	10.0	35.5	53.6	66.9	.85
68	Expansion	10	2000°-2200°F.	52.6	68.6	84.3	98.0	1.2	12.5	37.7	72.4	.80
68	BM-AGA	13	800°C.	29.5	55.3	78.1	97.3	.0	2.5	28.2	72.7	.76
63	Expansion	10	2300°-2500°F.	35.0	61.6	80.9	97.7	.0	2.9	23.8	71.9	.85
63	BM-AGA	18	800°C.	41.8	61.0	78.1	97.2	.0	3.4	21.2	68.5	.79

1/ Temperatures in this test were somewhat lower than those on the standard 2000° - 2200° F. cyrve.

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It would appear that, since expansion is caused by pressures developing in the plastic layers, some plastic property could be determined that would correlate closely with expansion. For example, it seems reasonable to assume that expansion should be proportional to the viscosity of the plastic mass or inversely proportional to the fluidity. Several schemes were tested, but perhaps the plot of the area under the Gieseler plastometer curve against expansion shows as good correlation as any other. The results are shown plotted on semilog paper in figure 23. The correlation is close enough to show that there is a relationship between expansion and fluidity, coal 63 being the farthest out of line. However, this coal is abnormal; from experience with coals in this range of rank and petrographic composition one would expect considerably higher fluidity, which would place the point close to the curve. It should be added that expansion in the sole-heated oven at constant pressure was taken as the abscissa in this plot, so that the numerical variation in expansion should be a maximum; furthermore, experience with this method of testing was greater than that for the others.

Figure 24 gives results for expansion determined in the sole-heated oven plotted against peak pressures obtained in the vertical-slot oven. Here, again, expansion at constant pressure in the sole-heated oven was chosen as one of the coordinates for the same reasons as given in the preceding section. The correlation is not bad, considering that the heating programs for all the points were not the same in both ovens. These results are interpreted to indicate that, when known discrepancies are ironed out and when more comparative data are available, there is prospect of substituting the simpler method of testing.

Small-Scale Low-Temperature Carbonization Assays. - Interesting relationships have been developed between the chemical composition of splint and of bright coal and their yields of primary carbonization products obtained by a small-scale (Fischer) low-temperature carbonization assay, all yields being upon the dry, mineral-matter-free basis.

For both splint and bright coals of bituminous rank:

Coke, percentage yield = (0.836 x fixed carbon, percent) + 23.4.

For bright coals:

Tar and oil, percentage yield = (0.805 x volatile matter, percent) - (1.05 x oxygen, percent) - 7.7.

For splint coals:

Tar + oil, percentage yield = (0.781 x volatile matter, percent) - (1.02 x oxygen, percent) - 6.2.

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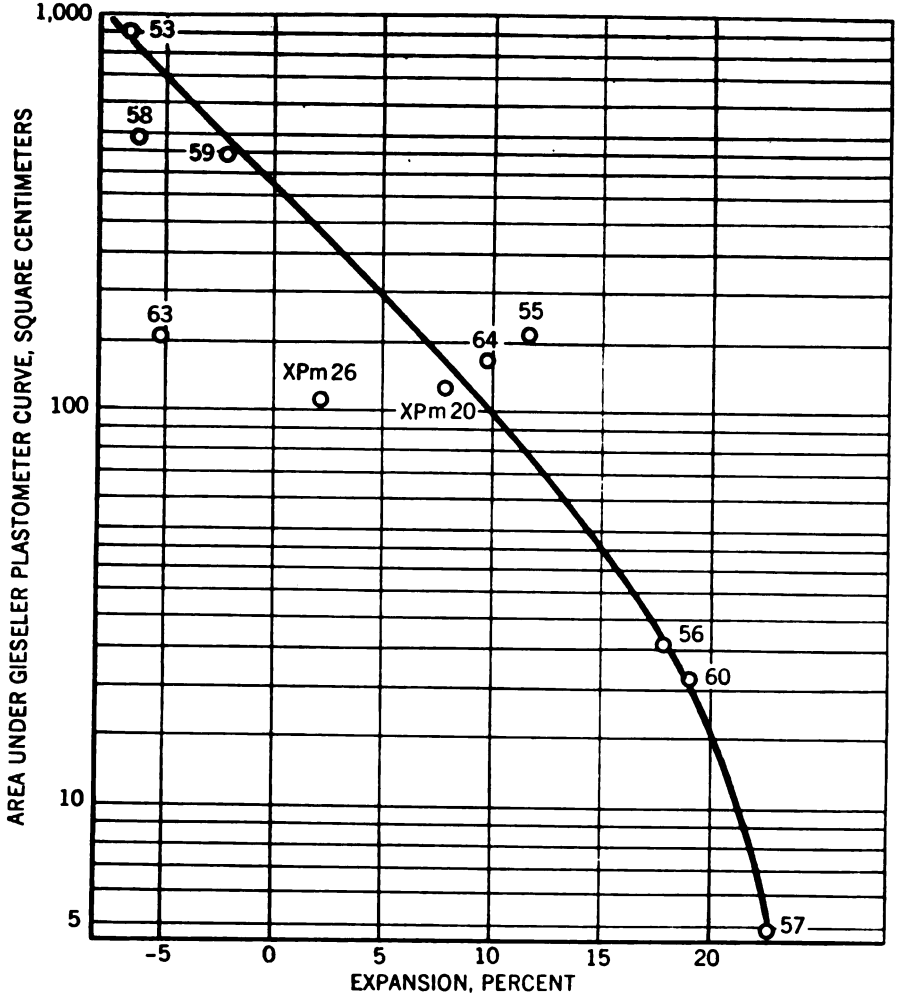

Figure 23.- Relation between area under Gieseler plastometer curve and expansion in sole-heated oven.

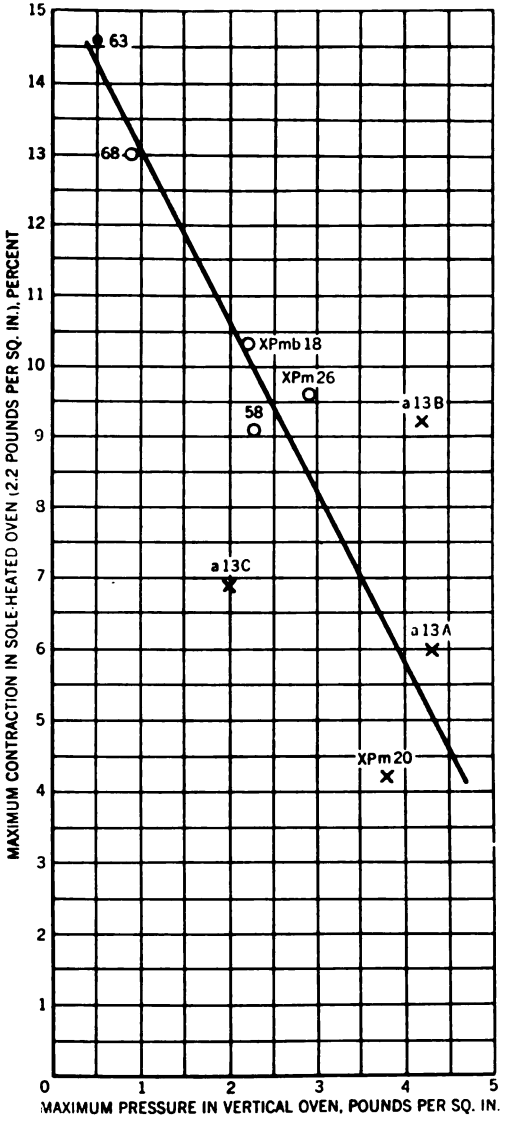

Figure 24.- Relation between results from sole-heated oven at constant pressure and those from vertical-slot oven at constant volume.

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Similar relationships have been worked out for the yields of water, carbon dioxide, and carbon monoxide.56/

Production of Liquid Fuels from Coal by Hydrogenation

The first of a series of publications describing the results obtained in this investigation has appeared. The investigation was undertaken in preparation for the time when gradual exhaustion of petroleum resources will require supplementing the supply of motor fuel with gasoline from coal to meet growing national requirements.

A small continuous unit capable of hydrogenating 100 pounds of coal in 24 hours was constructed and an assay procedure developed for determining the ease of hydrogenation of American coals.

Hydrogenation Assay of United States Coals in Continuously operated Experimental Plant

The experimental plant, assay procedure, and hydrogenation of nine coals of various ranks from high-volatile A bituminous to lignite have been described in detail.57/

During the past year, four additional high-volatile bituminous coals were hydrogenated in the experimental plant to determine the oil yield and the operating difficulties. The coals assayed were high-volatile A coals from the Upper Freeport (W. Va.) and the Black Creek (Ala.) beds; high-volatile B from the Lower Sunnyside (Utah) bed; and high-volatile C from the Indiana No. 4 bed.

The assay procedure consists of pumping a mixture of about equal parts of powdered coal and a heavy oil along with hydrogen under 200 to 300 atmospheres pressure into a vertical alloy-steel tube, 3 inches i.d. and 8 feet in length, heated to 430°-460° C. (806°-860° F.). The contact time and temperature are varied until a maximum yield of oil, carried out of the converter by the stream of hydrogen, is obtained. A heavy oil in which the ash of the coal, the unreacted coal, and the catalyst particles are suspended is discharged through a standpipe about 6 feet above the bottom of the converter. This heavy-oil slurry is centrifuged, and the resulting oil is mixed with another charge of coal and catalyst. Thus the assay

56/ Sprunk, G. C., Ode, W. H., Selvig, W. A., and O'Donnell, H. J., Splint Coals of the Appalachian Region; Their Occurrence, Petrography, and Comparison of Chemical and Physical Properties with Associated Bright Coals: Bureau of Mines Tech. Paper 615, 1940, 59 pp.

57/ Storch, H. H., Hirst, L. L., Fisher, C. H., and Sprunk, G. C., Hydrogenation and Liquefaction of Coal. Part 1. Review of Literature, Description of Experimental Plant and Liquid Phase Assays of Some Typical Bituminous, Subbituminous and Lignitic Coals: Bureau of Mines Tech. Paper 622, 1941, 110 pp.
Hirst, L. L., Storch, H. H., Fisher, C. H., and Sprunk, G. C., Hydrogenation and Petrography of Subbituminous Coals and Lignites: Ind. Eng. Chem., vol. 32, 1940, pp. 1372-1379.

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consists essentially of determination of the optimum conditions for the maximum oil yield consistent with complete regeneration of the tar-oil vehicle used in making a paste with the original coal. The assay product consists of about 20 percent of oil boiling in the gasoline range (to 205° C.) and 70 percent boiling from 205°-330° C. This oil contains 12 to 20 percent tar acids, and 2 to 4 percent tar bases. The remainder or neutral oil is 40 to 70 percent aromatic, and contains 20 to 40 percent saturates and 10 percent olefins. The saturates are 50 to 90 percent naphthenic, and the olefins are cyclic.

Table 16 summarizes the yield of oil and residue for all of the coals thus far hydrogenated in the experimental plant. Column 4 shows that, with two exceptions, there is a steady decrease in the oil yield based upon the moisture- and ash-free coal with decreasing coal rank. The coal of highest rank gave a lower yield than might be predicted, and the Monarch subbituminous coal yielded an appreciably greater amount of oil than was expected from a coal of this rank. The yield based upon the dry coal is somewhat erratic, owing to varying amounts of ash, and that based upon the coal as mined also shows eccentricities due to the ash content, as well as the influence of the moisture content that results in a more rapid drop with decreasing rank. The petrographically estimated amounts of organic residue given in column 7 agree reasonably well with those of column 8, which were obtained in the experimental plant.

Table 17 shows the amounts of tar acids, tar bases, neutral aromatic oils, and gas obtained in the coal-hydrogenation assays, as well as the amounts of hydrogen consumed. The oxygen and nitrogen contents of the coals may be correlated to a limited extent with the yield of tar acids and tar bases, respectively. There is no apparent explanation for the outstanding high yield of tar acids from Pittsburgh-bed coal. The low tar-acid yield for the Upper Freeport and the Black Creek coals is probably due to the higher operating temperatures used in hydrogenating these coals. These temperatures were in the range 455°-460° C. whereas 430°-440° C. was employed for most of the other coals. The tar acids boiling to 235° C. are approximately one-half of the total phenolic compounds and consist of about 50 percent xylenols, 30 percent cresols, and 20 percent phenol. Perhaps the most significant data of table 17 to be correlated with rank are those of column 9 for the total aromatic neutral oil. With two outstanding exceptions (Pittsburgh and Illinois No. 6 beds), there is a steady decrease in aromatic-oil yield with decreasing rank. Column 3 of table 17 shows that there is little, if any, trend with coal rank in the amount of hydrogen used per unit weight of moisture- and ash-free coal. The assays run at 4,500 lb. per sq. in. hydrogen pressure consumed more hydrogen than those conducted at 3,200 lb. This increased consumption was more marked for the higher-rank coals. The hydrogen used per ton of oil produced (column 3, table 17, divided by column 4, table 16) ranges from about 0.12 ton for bituminous coals to 0.15 ton for lignites; with the highest values of about 0.17 ton for the two bituminous coals hydrogenated at 4,500 lb. per sq. in. The increase from 0.12 to 0.15 ton of hydrogen per ton of oil is much smaller than might have been predicted from the oxygen contents (column 2, table 17) of the coals. This result apparently is due to removal of most of the oxygen as carbon dioxide rather than as water for oxygen contents greater than about 10 percent.58/

58/ Fisher, C. H., Eisner, A., Clarke, L., Fein, M. L., and Storch, H. H., Kinetics of Hydrogen Consumption, Oxygen Removal, and Liquefaction in Coal Hydrogenation, Effect of Rank II: Fuel in Sci. and Practice, vol. 20, 1941, pp. 5-13.

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TABLE 16. - Experimental plant-assays. Yield of residue and oil

1	2	3	4	5	6	7	8	9
		H_2O, percent of coal as mined	Oil yield, percent of-			Percent of dry coal		
			Moisture- and ash-free coal	Dry coal	Coal as mined	Organic residues		
Coal rank 1/	Bed and State					Predicted	Obtained	Ash
H.V.A. bit.	Mary Lee, Ala.	4.2	60	54	52	9.0	9.8	10.2
Do.	Upper Freeport, W. Va.	3.2	70	64	62	3.4	5.1	8.3
Do.	Pittsburgh, Pa.	1.6	70.5	65	64	7.8	4.0	5.7
Do.	Black Creek, Ala.	2.7	70.5	68	66	7.8	6.0	2.9
H.V.B. bit.	Lower Sunnyside, Utah	5.5	75	71	67	5.4	5.0	5.2
H.V.C. bit.	No. 4, Ind.	13.6	70	64	55	6.8	5.5	8.5
H.V.B. bit.	No. 6, Ill.	7.8	70.5	65	60	5.4	4.9	7.1
H.V.C. bit.	McKay, Wash.	9.6	68.5	66	59	0.5	1.1	4.1
Subbit. B	Puritan, Colo.	24.1	63	60	45	4.2	5.6	5.4
Do.	Rosebud, Mont.	25.1	60	55	40	8.2	6.7	10.1
Do.	Monarch, Wyo.	23.2	68.5	64	49	2.6	3.1	5.1
Lignite	Beulah, N. Dak.	34.9	54.5	50	31	7.6	9.7	12.3
Do.	Velva, N. Dak.	39.5	52	49	32	6.6	4.7	7.4

1/ H.V. = high-volatile; bit. = bituminous.

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TABLE 17. - Experimental-plant assays. Hydrogen used; yield of tar acids, tar bases, and total aromatic neutral oil
(Percent of moisture- and ash-free coal)

1	2	3	4	5	6	7	8	9	10
			Tar acids						
			Distilling						
Coal bed and state	Oxygen	Hydrogen used	Total yield	To 235°C	Between 235° and 300°C.	Nitrogen	Tar bases	Total aromatic neutral oil 1/	Gas
M. L., Ala.	5.0	8.5	7.6	4.3	2.6	1.8	2.5	32.8	27
U.F., W.Va.	5.7	2/ 12.0	5.3	2.9	2.1	1.5	2.0	34.3	26
Pgh., Pa.	6.8	9.0	12.2	7.5	3.7	1.7	2.8	40.9	21
B.C., Ala.	7.5	2/ 12.1	8.4	4.1	2.5	1.8	1.7	30.8	20
L.S.U.	9.5	7.5	10.9	5.1	4.0	1.6	2.6	29.8	13
4, Ind.	9.5	9.0	11.7	5.6	4.3	1.7	2.3	31.5	20
6, Ill.	10.0	8.5	15.1	6.0	4.2	1.9	1.7	37.1	17
M., Wash.	12.5	7.6	14.6	6.0	5.0	2.2	3.7	27.7	22
P. Colo.	16.4	9.7	12.6	7.4	4.2	1.6	2.8	28.2	26
R., Mont.	16.2	2/ 7.5	13.8	7.6	5.4	1.1	2.1	26.4	19
M., Wyo.	16.9	2/ 8.5	17.2	8.2	6.0	1.5	3.1	25.4	25
B., N. D.	19.4	8.0	12.0	5.6	5.2	1.0	1.6	23.5	28
V., N. D.	21.2	2/ 7.0	15.6	8.4	6.3	1.0	1.6	22.1	28

1/ In calculating total aromatics it was assumed that overhead oil boiling over 330°C. of table 4 was 80 percent aromatic.
2/ Assayed at 4,500 lb. per sq. in. hydrogen pressure; all other tests at 3,200 to 3,350 lb. per sq. in.

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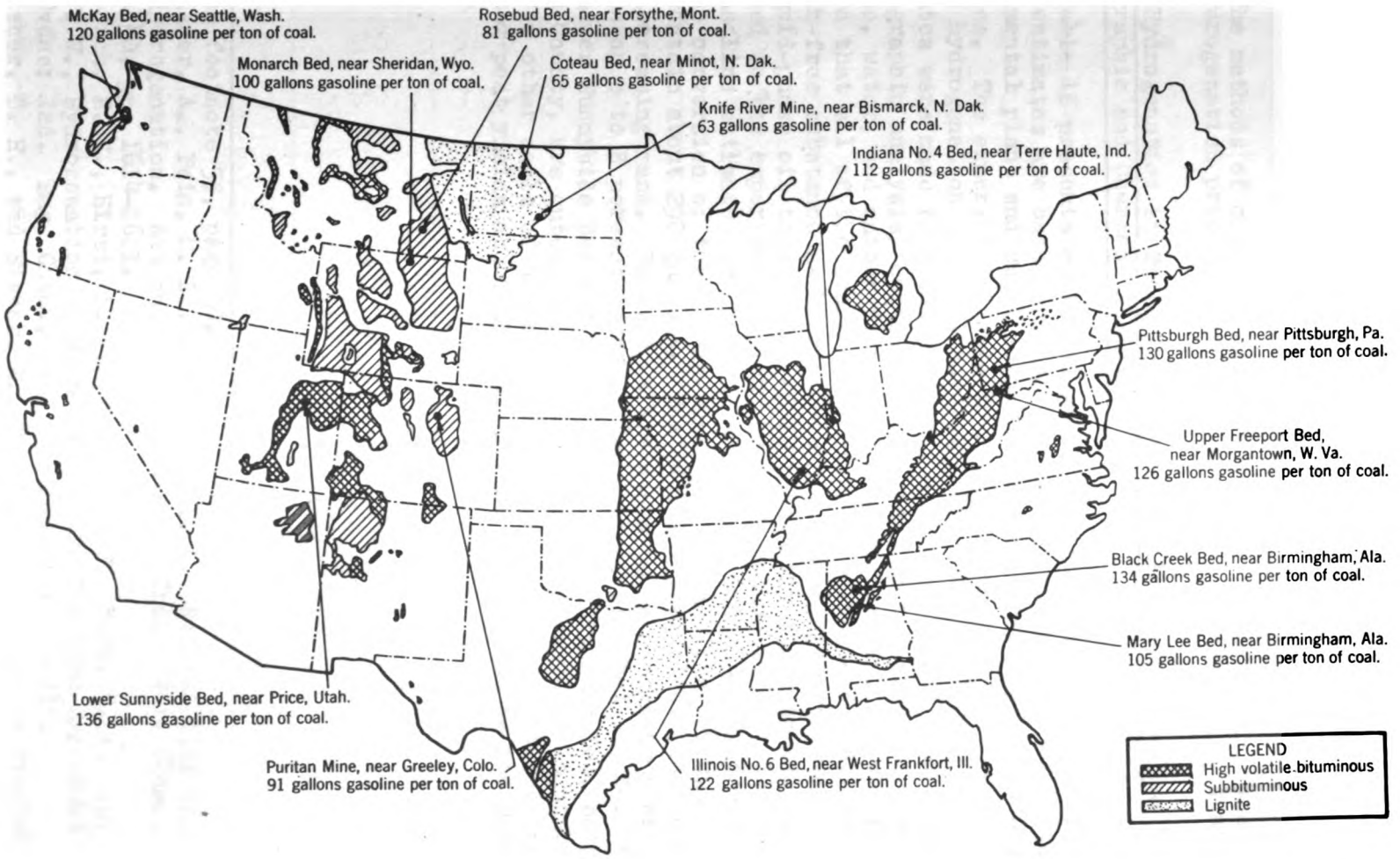
McKay Bed, near Seattle, Wash.
120 gallons gasoline per ton of coal.
Rosebud Bed, near Forsythe, Mont.
81 gallons gasoline per ton of coal.
Monarch Bed, near Sheridan, Wyo.
100 gallons gasoline per ton of coal.
Coteau Bed, near Minot, N. Dak.
65 gallons gasoline per ton of coal.
Knife River Mine, near Bismarck, N. Dak.
63 gallons gasoline per ton of coal.
Indiana No. 4 Bed, near Terre Haute, Ind.
112 gallons gasoline per ton of coal.
Pittsburgh Bed, near Pittsburgh, Pa.
130 gallons gasoline per ton of coal.
Upper Freeport Bed,
near Morgantown, W. Va.
126 gallons gasoline per ton of coal.
Black Creek Bed, near Birmingham, Ala.
134 gallons gasoline per ton of coal.
Mary Lee Bed, near Birmingham, Ala.
105 gallons gasoline per ton of coal.
Lower Sunnyside Bed, near Price, Utah.
136 gallons gasoline per ton of coal.
Puritan Mine, near Greeley, Colo.
91 gallons gasoline per ton of coal.
Illinois No. 6 Bed, near West Frankfort, Ill.
122 gallons gasoline per ton of coal.
LEGEND
High volatile bituminous
Subbituminous
Lignite

Figure 25.- Conversion of coal to gasoline. Yields from coals tested in Bureau of Mines hydrogenation plant.

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The estimated yield of gasoline from each of the coals thus far assayed in the experimental plant is shown in figure 25. This figure also shows the important bituminous, subbituminous, and lignitic coal beds of the United States.

The methods of chemical analysis used in characterizing the coal and tar hydrogenation products have been described in recent publications.59/

Batch Hydrogenation in Small Autoclaves; Prediction of Gasoline Yields from Petrographic and Chemical Analyses

Table 18 presents estimated gasoline yields for a number of coals. These estimates are based upon correlation of the results of tests in the experimental plant and small autoclave tests with petrographic and chemical analyses. The experimental data in column 10 of this table were obtained by the hydrogenation of small samples (100 grams) in 1.2-liter autoclaves. Estimates were made from the moisture, ash, oxygen, and opaque matter (petrographic analysis) content of the coal, of the probable yield of residue, water, and carbon dioxide upon hydrogenation. It was further assumed that all of the coals would yield 20 percent of their moisture- and ash-free substance as hydrocarbon gases upon hydrogenation. The yield of liquid-phase oil thus predicted is reasonably close to that actually obtained in the experimental plant (compare column 12 with 13, table 18). The gasoline estimates are made by assuming a weight-percent yield of 70 for the conversion of the liquid-phase oil to gasoline, of which 1 ton will contain about 290 gallons. The gasoline yield tends to decrease with decreasing rank. However, there seems to be a maximum yield for coals containing 6 to 8 percent oxygen. Two Utah coals, that is, No. 16 (table 18), Lower Sunnyside Bed and No. 21 (table 18), Hiawatha Bed, both from Carbon County, are outstanding in that the gasoline yield is higher than that for other coals of about the same rank. It is of interest that dehydrated peat yields about the same amount of gasoline as the Dakota lignites.

59/ See footnote 58, page 50.
Eisner, A., Fein, M. L., and Fisher, C. H., Neutral Oils from Coal Hydrogenation. Action of Sulfuric Acid: Ind. Eng. Chem., vol. 32, 1940, pp. 1614-1621.
Storch, H. H., Hirst, L. L., Fisher, C. H., Work, H. K., and Wagner, F. W., Hydrogenation of High-Temperature Tar from Byproduct Coke-Ovens: Ind. Eng. Chem., vol. 33, 1941, pp. 264-274.
Fisher, C. H., and Eisner, A., Tellurium Compounds as Friedel-Crafts Catalysts, The Oxidation of Organic Compounds with Tellurium Dioxide: Jour. Organic Chem., vol. 6, 1941, pp. 169-174.

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TABLE 18. - Predicted yields from petrography and small autoclave tests

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
	Origin and rank of coal			Analyses, weight percent					Residue[1] weight percent of moisture-free coal			Yield, gallons per ton of coal as mined		
				As received		Moisture- and ash-free	Moisture-free					Liquid-phase oil		Gasoline
	Coal bed; mine	County; State	Rank	Moisture	Ash	Oxygen	Opaque attritus	Fusain	Predicted	Autoclave	Expt'l Plant	Predicted[2]	Expt'l plant	predicted[3]
1	Upper Banner Clinchfield No. 9	Dickenson Virginia	Bit. H.V.A	1.6	4.3	4.3	21	2	14.8	-	-	178	-	136
2	Mary Lee Sayreton	Jefferson Alabama	do.	4.2	9.8	5.0	5	7	19.2	-	20.0	165	135	105
3	Elkhorn No. 1 Garret[4]	Floyd Kentucky	do.	1.4	4.6	5.5	49	0	24.2	23.0	-	154	-	117
4	Upper Freeport Ind. Coll. No. 1	Monongalia West Virginia	do.	3.2	8.0	5.7	6	1	11.7	-	13.4	182	164	126
5	---- Paulcille[4]	Webster West Virginia	do.	1.5	18.7	6.0	15	0	25.2	27.2	-	146	-	112
6	Alma Spruce River No. 4	Boone West Virginia	do.	2.1	7.1	6.3	14	5	13.4	-	-	178	-	136
7	Pittsburgh Bruceton	Allegheny Pennsylvania	do.	1.6	5.6	6.8	12	3	13.5	-	9.7	177	170	130
8	Chilton Boone No. 2	Logan West Virginia	do.	2.2	4.3	7.4	10	3	11.4	-	-	178	-	136
9	Black Creek Empire	Walker Alabama	do.	2.7	2.8	7.5	7	5	10.7	-	8.9	181	175	134
10	Raton Dawson No. 6	Colfax New Mexico	Bit. H.V.B	2.2	12.1	7.6	10	2	18.2	-	-	161	-	123
11	No. 2 Gas Bed Point Lick No. 4	Kanawtia West Virginia	Bit. H.V.A	1.9	2.7	7.8	12	3	10.6	-	-	181	-	138
12	High Splint Closplint	Harlan Kentucky	do.	3.3	3.7	8.2	26	2	16.2	-	-	164	-	126
13	----[4] Canfield	Mahoning Ohio	do.	2.2	15.9	8.4	18	0	22.3	23.6	-	147	-	113
14	Kemmerer No. 5 Gomer No. 5	Lincoln Wyoming	Bit. H.V.B	2.5	3.9	9.2	24	2	15.6	-	-	164	-	126

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TABLE 18. - Predicted yields from petrography and small autoclave tests (Cont'd.)

1	2	3	4	5	6	7	8	9	10	11	12	13	14
Origin and rank of coal			Analyses, weight percent					Residue1/ weight percent of moisture-free coal			Yield, gallons per ton of coal as mined		
			As received		Moisture-and ash-free	Moisture-free					Liquid-phase oil		Gasoline
Coal bed; mine	County; State	Rank	Moisture	Ash	Oxygen	Opaque attritus	Fusain	Predicted	Autoclave	Expt'l plant	Predicted2/	Expt'l plant	predicted3/
Illinois No. 2	Woodford												
15 Minok	Illinois	Bit. H.V.C	10.7	5.2	9.2	5	1	8.8	-	-	166	-	127
Lower Sunnyside	Carbon												
16 Columbia	Utah	Bit. H.V.B	5.5	4.9	9.5	6	3	10.6	-	10.2	170	178	136
Indiana No. 4	Vigo												
17 Saxton No. 1	Indiana	Bit. H.V.C	13.6	7.4	9.5	7	4	15.4	-	14.0	144	146	112
Illinois No. 6	Franklin												
18 Orient No. 2	Illinois	do.	7.8	6.5	10.0	1	5	12.5	-	12.0	160	159	122
Upper Shaw	Lower Mantanuska												
19 Eska	Alaska	do.	3.6	9.6	10.0	3	1	12.2	-	-	168	-	129
Green River	Muhlenberg												
20 Green River	Kentucky	do.	11.0	7.2	10.1	4	4	13.7	-	-	151	-	116
Hiawatha	Carbon												
21 King No. 1	Utah	Bit. H.V.A	2.8	5.3	10.2	9	1	9.1	9.7	-	176	-	135
Rock Springs No. 3	Sweetwater												
22 Gun Quealy	Wyoming	Bit. H.V.C	6.1	2.5	11.0	6	2	7.1	-	-	173	-	132
No. 8	-----												
23 Jonesville	Alaska	do.	4.9	13.1	11.0	3	0	15.1	-	-	155	-	119
Spring Canyon No. 1	Carbon												
24 No. 2 West	Utah	Bit. H.V.B	3.7	7.1	11.1	6	1	11.2	11.6	-	166	-	127
Sand Coulee	Cascade												
25 Giffen No. 1	Montana	do.	2.7	28.7	11.3	27	5	45.3	41.0	-	86	-	66
Rock Springs No. 15	Sweetwater												
26 D.O. Clark	Wyoming	Bit. H.V.C	12.6	1.7	12.0	10	2	8.0	-	-	156	-	120
-----	King												
27 Taylor	Washington	Bit. H.V.B	4.0	17.4	12.4	2	0	18.4	22.5	-	138	-	106
McKay	King												
Strain-Upper													
28 Diamond	Washington	Bit. H.V.C	9.6	3.7	12.5	1	0	4.5	5.6	5.2	166	156	120

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TABLE 18. - Predicted yields from petrography and small autoclave tests (Cont'd.)

1	2	3	4	5	6	7	8	9	10	11	12	13	14
Origin and rank of coal			Analyses, weight percent					Residue[1] weight percent of moisture-free coal			Yield, gallons per ton of coal as mined		
					Moisture- and ash-free	Moisture free					Liquid-phase oil		Gasoline
Coal bed; mine	County; State	Rank	As received Moisture	Ash	Oxygen	Opaque attritus	Fusain	Predicted	Autoclave	Expt'l plant	Predicted[2]	Expt'l plant	predicted[2]
29 Roundup Prescott	Musselshell Montana	Subbit. A	10.5	6.6	12.5	15	3	16.4	20.2	-	129	-	99
30 Rock Springs No. 9 D.O. Clark	Sweetwater Wyoming	do.	11.0	1.4	12.5	6	2	6.0	-	-	162	-	124
31 Kemmerer No. 1 Brilliant No. 8	Lincoln Wyoming	Bit. H.V.C	6.2	5.1	12.8	9	2	11.0	-	-	157	-	120
32 Gallup American Coal Co. No. 5	McKinley New Mexico	Subbit. A	11.9	8.3	12.9	14	1	16.0	-	-	135	-	103
33 Rock Springs No. 7 D.O. Clark	Sweetwater Wyoming	do.	11.9	2.3	13.1	7	2	7.4	-	-	155	-	119
34 No. 3-1/2 Navajo No. 5	McKinley New Mexico	do.	15.0	5.9	13.4	11	2	13.3	-	-	135	-	103
35 Mammoth Gantor	Musselshell Montana	do.	13.4	5.2	13.8	5	2	10.0	11.3	-	143	-	110
36 Rock Springs No. 1 Union Pac. "D"	Sweetwater Wyoming	do.	13.9	2.6	13.8	7	2	7.8	-	-	148	-	113
37 ——4/ Prospect	Sevier Utah	do.	7.0	4.6	14.0	4	0	6.5	11.2	-	159	-	122
38 No. 3 Smith	Carbon Montana	do.	10.0	9.6	14.3	2	1	12.5	13.6	-	139	-	114
39 Rock Springs No. 7-1/2 Winton	Sweetwater Wyoming	do.	15.6	2.1	15.1	7	2	7.3	-	-	142	-	109
40 No. 9 Grand Ridge	King Washington	Subbit. B	13.5	13.7	15.4	1	0	16.4	20.7	-	120	-	92
41 Weber Wasatch	Summit Utah	Subbit. A	12.2	3.5	15.5	9	1	8.6	14.9	-	136	-	104
42 Rock Springs No. 1 Winton	Sweetwater Wyoming	Subbit. B	16.5	1.7	15.5	6	2	6.4	-	-	142	-	109
43 Rosebud Colstrip	Rosebud Montana	do.	25.1	7.6	16.2	13	3	17.3	19.5	16.8	102	106	81

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TABLE 18. - Predicted yields from petrography and small autoclave tests (Cont'd.)

1	2	3	4	5	6	7	8	9	10	11	12	13	14
Origin and rank of coal			Analyses, weight percent					Residue1/ weight percent of moisture-free coal			Yield, gallons per ton of coal as mined		
Coal bed; mine	County; State	Rank	As received		Moisture- and ash-free	Moisture-free					Liquid phase oil		Gasoline
			Moisture	Ash	Oxygen	Opaque attritus	Fusain	Predicted	Autoclave	Expt'l plant	Predicted2/	Expt'l plant	predicted3/
-----	Weld Colorado	Subbit. B	24.1	4.1	16.4	10	4	13.4	12.9	11.0	115	119	91
44 Puritan	Campbell												
Roland-Smith	Wyoming	Subbit. C	29.4	6.1	16.8	7	1	12.4	14.6	-	103	-	79
45 Wyodak	Sheridan												
Monarch	Wyoming	Subbit. B	23.2	3.9	16.9	4	1	7.7	7.2	8.2	124	130	100
46 Monarch No. 45	Fremont												
Hudson	Wyoming	do.	23.0	4.1	17.0	9	2	10.9	-	-	117	-	90
47 Hudson No. 2	Sheridan												
Carney	Wyoming	Subbit. A	23.3	4.4	17.4	15	4	15.7	-	-	106	-	81
48 Acme	Coos												
Beaver Hill	Oregon	Subbit. B	17.4	3.5	18.0	2	0	5.0	10.4	-	130	-	100
49 Thomas	Wood												
Alba	Texas	Lignite	32.7	7.5	19.2	20	3	22.1	19.0	-	80	-	61
50 -----	Mercer												
Knife River Co.	North Dakota	do.	34.9	8.0	19.4	14	2	19.9	19.9	22.0	78	82	63
51 Beulah, N.D.	Lewis												
No. 1	Washington	do.	23.9	8.6	20.6	3	0	12.5	14.2	-	100	-	77
52 Reliance	Ward												
Truax-Trauer Co.	North Dakota	do.	39.5	4.5	21.2	9	3	13.9	11.0	12.1	82	85	65
53 Velva, N.D.	King												
Auburn, Wash	Washington	Brown coal	52.6	5.2	29.9	9	0	13.5	13.0	-	46	-	35
54 Youngblood	Manitowoc												
Hawk Island	Wisconsin	Peat	11.9	10.4	32.2	4	0	13.4	14.0	-	79	-	61
55 Swamp													

1/ Does not include catalyst.

2/ Prediction based upon 9 percent (on moisture-and ash-free coal) hydrogen consumption, complete oxygen removal (as water for oxygen contents up to 10 percent, and beyond 10 percent, half as water and half as carbon dioxide); gas loss, 20 percent, average of autoclave and predicted residues, and 265 gallons of oil per ton.

3/ Prediction based upon assumption of 70 percent by weight of liquid-phase oil converted to gasoline, and 290 gallons per ton of gasoline.

4/ Cannel coal.

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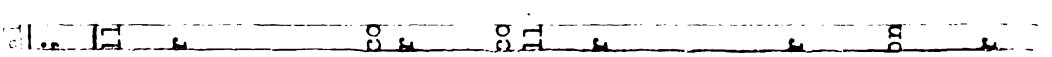

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Rates and Mechanisms of Coal-Hydrogenation Reactions; Effect of Catalyst

A series of experiments with one coal in the presence and absence of catalyst has been completed. This work was done in 1.2-liter autoclaves, using 1 percent stannous sulfide as catalyst, and in a glass liner when no catalyst was desired. Two temperatures - 385° and 400° C. - were employed. Curves of the amount of hydrogen used and of oxygen eliminated plotted against time (up to 15 hours) were obtained for both temperatures at constant pressure (1,000 pounds initial, "cold", pressure of hydrogen). The results show that whereas the presence of the catalyst markedly increases the rate of hydrogen consumption, the rate of oxygen elimination at 400° C. was virtually the same in the presence or absence of a catalyst. At 385° C., however, the rate of elimination of oxygen was appreciably greater in the presence of a catalyst. These results are being studied in preparation for their publication and for further research. Their apparent meaning is that the oxygen-elimination reactions are largely noncatalytic and probably consist in the transfer of hydrogen from simple hydroaromatic compounds to the dissociated coal substance. The chief function of the catalyst would therefore be to increase the rate of regeneration of the active hydroaromatic compounds.

Hydrogenation of High-Temperature, Byproduct Coke-Oven Tar

Several long runs were made in the experimental plant on the destructive hydrogenation of coke-oven tar and fractions thereof, such as heavy tar distillate, and of pitch oil obtained by carbonization of coal-tar pitch. All of the work was done in liquid phase, the objective being to determine the efficiency of conversion of these materials to an oil boiling in the range 200°-355° C. which would be useful as a wood preservative. These experiments were made in cooperation with the Koppers Co. of Pittsburgh, Pa.

Conversion of Coal-Hydrogenation Middle Oils into Gasoline by Vapor-Phase Hydrogenation

The vapor-phase hydrogenation of middle oils from the liquid-phase hydrogenation of two high-volatile A bituminous coals showed that for the oil from the higher-rank coal (86.1 percent carbon on moisture- and ash-free basis) the yield of gaseous hydrocarbons was approximately equal to the yield of gasoline, whereas for the oil from the coal of somewhat lower rank (84.2 percent carbon) the yield of gas was much smaller, namely about 60 percent of the yield of gasoline. When an alumina-molybdic acid catalyst is used, the gasoline obtained from Pittsburgh-bed (Bruceton mine) coal was of 73.5 octane number (C.F.R. Motor Method) and addition of 3 cc. tetraethyl lead per gallon resulted in an octane number of 81.9.

Mechanism of Combustion and Explosion of Gaseous Fuels

As part of a program concerning the rates and mechanisms of the combustion of gaseous fuels, a study has been made of the fundamentals of

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the hydrogen-oxygen reaction. Following the analysis of data on this reaction by Kassel and Storch and by von Elbe and Lewis,[60] a series of experiments was done on the nature of the third explosion limit.[61] The results obtained are partly explained by the mechanism postulated by von Elbe and Lewis. The explosion is preceded by an induction period, which decreases to zero as the pressure is increased. Such third-limit explosion pressures of zero induction period are representative of the isothermal branched-chain explosion, whereas lower-third-limit explosion pressures with induction periods are characterized by both isothermal branched chains and by thermal disturbances.

Water has a powerful effect in depressing the second limit and increasing the third limit, the effect being due to a decrease in chain branching.[62]

Coating the walls of the reaction vessel with various salts resulted in large changes in rate because of variations in the efficiency of chain breaking at the wall. Below 530° C. the reaction is mainly heterogeneous.

Stationary Flames

A study of the mechanics of the stationary flame (Burnsen type) is being made. In particular, information is desired concerning the cross-sectional distribution of velocity and direction of flow of the gases emerging from the orifice and entering and leaving the flame cone. An apparatus for this purpose has been built. A long, narrow beam of light is passed through the midsection of the flame in the longitudinal direction. The stream of combustible gas picks up a few particles of finely powdered aluminum on passing through a specially constructed device. Light is reflected from the particles in the beam into a camera, which is placed to receive at right angles to the beam. This light is interrupted by slots in a wheel 20 inches in diameter, rotating at known speed. Thus there is obtained in the film a series of interrupted vertical lines over

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60/ Kassel, L. S., and Storch, H. H., Chemical Kinetics of the Reaction of Oxygen with Hydrogen and with Deuterium: Jour. Am. Chem. Soc., vol. 57, 1935, pp. 672-678.
Elbe, G. von, and Lewis, Bernard, The Reaction between Hydrogen and Oxygen above the Upper Explosion Limit: Jour. Am. Chem. Soc., vol. 59, 1937, pp. 656-662.

61/ Heiple, H. R., The Thermal Reaction Between Hydrogen and Oxygen; Kinetics of the Third Explosion Limit. Inhibition of the Explosive Reaction by Metallic Silver. Ph. D. Thesis, University of Pittsburgh, Pittsburgh, Pa. 1941: Results of Bureau of Mines - School of Engineering, University of Pittsburgh fellowship.
Heiple, H. R., and Lewis, Bernard, The Reaction Between Hydrogen and Oxygen; the Third Explosion Limit: Jour. Chem. Phys. (in press).

62/ Elbe, Guenther von, and Lewis, Bernard, The Reaction Between Hydrogen and Oxygen; the Upper Explosion Limit and the Reaction in Its Vicinity: Jour. Chem. Phys., vol. 9, 1941, pp. 194-195.
Heiple, H. R., and Lewis, B., The Reaction between Hydrogen and Oxygen in the Presence of Silver; the Third Explosion Limit: Jour. Chem. Phys., vol. 9, 1941, pp. 120-121.

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the cross section of the stream, the length of which is a measure of the speed of the particle and therefore of the gas stream at that point, as the particle has little inertia.

Preliminary photographs of a gas stream issuing from the orifice with streamline flow show a parabolic distribution of velocity across the stream, as is found in fluids traveling in pipes. As the stream travels upward, momentum transferred from the faster-moving central layers and friction at the stationary boundary flatten the velocity distribution. The layers near the boundary seem first to receive energy from the central layers, increasing their velocities only to decrease again owing to friction at the boundary.

It is well-known that the gas stream, on emerging from the conical flame front, suffers a change in direction or refraction. The question as to where this refraction[63] occurs, that is, as the gas is passing through the flame front or before or after passage, can be determined by photographing particles in the stream of a Bunsen flame. Preliminary photographs show that the change in direction of the stream occurs just before it enters the flame front.

[63] Lewis, Bernard, and Elbe, Guenther von, Flame Temperature: Jour. Appl. Phys., vol. 11, 1940, pp. 698-706.

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